An Assessment of Factors Affecting the Spatial Distribution of Audubon's Shearwater (*Puffinus l. lherminieri*) throughout the Caribbean

by

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Abstract:

This study aims to better understand the factors that contribute to Audubon's Shearwater (*Puffinus l. lherminieri*) nesting sites on islands across the Caribbean region. Using locational presence and absence data of their breeding colonies a Geographical Information System (GIS) is used to determine the proximity and presence of a variety of marine (SST, bathymetry and derived bathymetry data) and terrestrial (elevation derived statistics) environmental variables that may influence nesting locations. For each location in the dataset, a set of nearshore (within 50 km) and offshore (50 and 300 km) metrics are calculated. Each selected variable is tested for statistical significance both in the nearshore and offshore locations. Logistic regression analysis is used to predict the presence and absence of sites. It is determined that a combination of bathymetry, sea surface temperature (SST), and ocean front proxies are the best variables for predicatively modeling Audubon's Shearwater nesting locations. A different subset of SST metrics and SST front proxies predict colony presence and absence when considering the offshore data. Both models have a predicative accuracy of 62.72%, with a degree of uncertainty arising from the quality of the presence and absence data. It is likely the relative success of both nearshore and offshore logistic regression analyses is linked to the respective, and differing, ecological roles that males and females play in the pre-laying exodus in this species. Despite the difficulty of detecting true absence data for this study, the results suggest that there is a great need to better understand the differential sex roles of Audubon's Shearwater and their breeding behavior to assist in future conservations efforts of the species.

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Preface

Preface 1.1: Research History

The genesis of this project has its roots in an attempt to identify suitable breeding habitat for Audubon's Shearwater on the island of Saba in the Netherlands Antilles. The goal of the project as it was originally conceived was to determine if Audubon's Shearwater habitat could be mapped across the island using surface metrics in a Geographic Information System (GIS). A combination of habitat information for breeding Audubon's Shearwaters was to be collected, based on a selection of terrestrial variables, including slope, elevation, aspect, and percent vegetation cover around the breeding sites. Although Audubon's Shearwaters are known to breed on Saba (Collier et al. 2002), this initial approach was determined to be unfeasible because no burrows of breeding Audubon's Shearwaters were found to determine optimal nesting conditions. Further work to find nesting sites was deemed too difficult for this project due to the inaccessibility of Saba's cliffs for detailed exploration. The cliffs of Saba are composed of fragile, highly friable rock that cannot be safely traversed even with appropriate climbing gear (A. J. Delnevo, *personal communication*).

After it was determined that finding individual nests would prove to be impossible, the project was changed to characterizing the landscape of the areas in which Audubon's Shearwaters were known to be breeding locations that had been identified by the presence of the birds' nocturnal flight calls. The physical characteristics of these sites were going to be analyzed using GIS and compared to the characteristics of sites where shearwaters were not known to be nesting. A statistical analysis was intended to identify the values in terms of slope and aspect that would limit the breeding locations for Audubon's Shearwater. However, after an initial review of

the literature, an inherent flaw was discovered in this research design. While Audubon's Shearwaters are almost exclusively cavity nesters (Mackin 2004; Snow 1965; Trimm 2004) they do not use cliffs exclusively. While they do nest in cliffs in some regions, such as the Galapagos and Réunion Island (Brentagnolle et al. 2000; Snow 1965), elsewhere they nest on flat ground under boulders and vegetation or even in burrows within the sand (Schreiber and Lee 2002; Trimm 2004).

Following these preliminary explorations, it was hypothesized that a more probable cause driving their breeding site distribution was the availability of food sources. Due to Audubon's Shearwater's practice of feeding exclusively on marine prey, it was determined that oceanic variables that could affect prey distribution would be more promising for analysis. It was also determined that Saba, due to its small size, did not represent a sufficiently large sample for a productive analysis. To address this issue, the problem of breeding site selection was expanded to include all available Audubon's Shearwater breeding site data for the entire Caribbean. With the inclusion of multiple variables and a binomial presence/absence data structure, it was decided that the best method of analysis to use was multivariate binomial logistic regression. As the research progressed, complexity of the analysis changed and was then modified to the point when it emerged in its final form as presented in this thesis.

Preface 1.2: Organization of the Paper

Following this introduction to the thesis, the second section is formatted as a manuscript to be submitted to a journal. The introduction provides the basic review of literature for the article being submitted to the journal *Ecological Applications*, published by the Ecological Society of America. It provides an overview of the previous work on Audubon's Shearwater in

the Caribbean and seabird modeling in general. The introduction concludes by setting out the individual goals of the paper its primary conclusions. The methods section is geared primarily to a readership comprised of biologists (which is reflective of the journal), and provides only an outline of the GIS methodology. It emphasis is however, on the statistical methods employed in the research. The results section contains appropriate tables and nine figures, one of which shows the results of one of the GIS methodologies, and eight maps illustrating results of the different analyses that were performed. The discussion focuses primarily on the role of what is known as the pre-laying exodus as the likely causative force behind the patterns observed in the results, as well as the role of the study in future conservation efforts for the species. A post-manuscript conclusion section expands on the major changes to the methodology in light of what is now suspected about the role of the pre-laying exodus. It also outlines three further projects that could be undertaken as an extension and continuation of the research conducted.

An Assessment of Factors Affecting the Spatial Distribution of Audubon's Shearwater (*Puffinus l. lherminieri*) Throughout the Caribbean

Introduction

Audubon's Shearwater (*Puffinus lherminieri,* Lesson 1839) is a small seabird with a body that is black above and pure white below, weighing between 180g-230g, and about 30cm in length with a wingspan of about 70cm and pantropical distribution (Howell 2012). Within the Caribbean, there is an estimated population of 8,000 individuals, comprising approximately 3,000-5,000 nesting pairs which represents a decline in number from the beginning of the 20th century (BirdLife 2008; Schreiber and Lee 2002; USFWS 2011). Included within the Caribbean population are the nominate *P. l. lherminieri* and the nearly extinct *P. l. loyemilleri* subspecies (Balloffet et al. 2006). In order to aid in future conservation efforts, a more thorough understanding of the oceanographic and terrestrial variables which drive the large-scale breeding distribution of this species in the Caribbean is required.

Relatively little work on Audubon's Shearwater has been conducted in the Caribbean in the context of understanding the spatial nature of their breeding distribution. The primary work on this species in the Caribbean has focused on their breeding ecology and behavior at single colonies in the Bahamas (Mackin 2004; Mackin 2009; Trimm 2004; Trimm and Hayes 2005). Recently, ecological niche models were used to identify possible breeding colonies of Audubon's Shearwater off the Brazilian coast (Lopes et al. 2014). This study analyzed several oceanographic variables, including bathymetry and sea surface temperature (SST), both of which were used in this study. The investigators employed the Maxent algorithm to produce an ecological niche model using a small sample size from a limited geographic area (Lopes et al. 2014).

Oceanic variables have been utilized in a wide variety of studies that model seabirds. Due to their effects on concentrating seabirds, sea surface temperature and bathymetric metrics have been used to identify marine 'hot spots' off California (Nur et al. 2011). Chlorophyll concentrations have shown to be important in affecting the foraging ecology of multiple pelagic seabird species (Vilchis et al. 2006). Other combinations of these variables have been used to explain seabird distributions during upwelling periods (Ainley et al. 2005), and to explain the breeding distribution of multiple seabird species in the Northwest Atlantic (Huettmann and Diamond 2001). Certain physical oceanographic data, such as isobaths, have been used for both 'hot spot' detection (Nur et al. 2011) and seabird distribution modeling in the South Pole (Ainley et al. 1998). This study employs a new class of features- bathymetric breaks- for the purpose of determining breeding distributions.

Rather than focusing on a small geographic area, this study uses breeding distribution presence and absence data for the entire Caribbean (Bradley and Norton 2009). Using a GIS as an organizing platform, potentially significant oceanographic and terrestrial variables that may influence the breeding distribution of Audubon's Shearwater are identified. Oceanographic variables are selected to identify potential food resource areas that can sustain large bird populations. The inclusion of terrestrial variables, particularly slope, is suggested by the presence of several exceptionally large colonies of Audubon's Shearwaters nesting in cliff cavities on Saba in the Netherlands Antilles, Réunion Island in the Indian Ocean, and on the Galapagos Islands (Brentagnolle et al. 2000; Snow 1965). The subset of variables that exhibit statistical significance at differentiating presence from absence sites are used in logistic regression to

determine which exact combination of variables yields the best predicative model of Audubon's Shearwater nesting sites.

Because Audubon's Shearwaters are known to have extensive habitat ranges, the final question this study aims to address is whether distance has a significant impact on breeding locations. To address this question, the analysis divided ocean variables into two distinct zones (Near and Pelagic) based on distance to presence and absence sites. In addition to assessing how Audubon's Shearwater use food resources during breeding, it may also reflect the sexual-dimorphism inherent in the post-copulation mass emigration of females (and occasionally males) from the breeding colony, known as the pre-laying exodus (Warham 1990). The zonal nature of the analysis allows for some speculation as to which sex plays a more important role in determining the breeding distribution of the birds.

Methods

Methods 1.1: Data Collection and Processing

Bird observational data.- Breeding presence information in the form of presence and non-presence or absence are taken primarily from Bradley and Norton (2009), but also from A. J. Delnevo, (*unpublished data*), Hodge (2011), and Levesque and Yésou (2005). Audubon's Shearwater 'presence' indicates that at least one nest was found in at least one year. A total of 94 Audubon's Shearwater 'presence' sites were identified and mapped in a GIS. The 'absence' sites used in this study comprised a subset of those presented in Bradley and Norton (2009). 'Absence' sites are those locations where field surveys had been conducted in one or more years, but where no Audubon's Shearwaters were recorded. To create a balanced dataset without 'absence' prevalence, a subset dataset of the nearly 700 potential 'absence' sites in Bradley and Norton (2009) is created. Whereas many locations lacking Audubon's Shearwater in Bradley and Norton (2009) listed only one to two pairs of breeding seabirds as being present, for this study 'absence' sites were chosen to be used only when relatively large numbers of breeding seabirds were found. This approach indicated that the sites had a higher potential to be attractive to Audubon's Shearwaters as breeding sites due to the higher numbers of other breeding seabirds, even though they were not recorded. A total of 75 'absence' sites were generated from the available data sources using this methodology.

All 'presence' and 'absence' sites were plotted in Google Earth (Google Inc., 2013) then converted into an ArcGIS shapefile (ESRI ArcMap 10.1) for further manipulation. A database was constructed within the GIS detailing numerous attributes about the sites, for example;

'presence' or 'absence' status, site name, months of incubation, and latitude and longitude of site. Of particular interest were data pertaining to both the known or suspected egg incubation period for each colony. For colonies where this information was missing and for 'absence' sites, an estimation of that period was based on a nearby 'presence' sites with the information. For colonies where only nestlings were found, the timing of the incubation was extrapolated using the 49-day egg incubation period of Audubon's Shearwater (Mackin 2004).

Environmental data.- To assist in identifying ocean resource sites for Audubon's Shearwater, monthly Chlorophyll-a (CHL) and sea surface temperature data from the MODIS/AQUA satellite was acquired from the NASA Near Earth Observatory for each month from January 2003 to December 2013. This data have a spatial resolution of 0.1 angular degrees (this is approximately 11113m^2 at the equator, but varies with latitude). The monthly data was averaged over the 11-year period using ArcMap to create a single temporally averaged raster for each month. Missing data, whether from sensor errors or cloud coverage was interpolated and filled using a custom, temporal autocorrelation-based Python script (Python Software Foundation, 2013) (Chatfield-Taylor and Li, *in prep*). All Python scripts used in this study were written by the author and were GIS-based. All scripts made use of the ArcPy (ESRI) Python module for performing GIS operations, and were executed using ArcMap. The bathymetric data were obtained from the General Bathymetric Chart of the Oceans (GEBCO_08; 2014), which has a spatial resolution of 30 arc-seconds (approximately 926m^2 at the equator). The spatial extent of the files is approximately from 97˚W to 56˚W and 32˚N to 4˚N.

Terrestrial elevation data were obtained from a void-filled version of NASA Shuttle Radar Topographic Mission (SRTM) 90m^2 Digital Elevation Model (DEM) dataset (Jarvis et al. 2008). The DEMs were converted into slope data using ArcMap, and both the DEM and slope

data were individually analyzed using custom Python scripts. Several other terrestrial variables were considered initially, including percent vegetation cover and percent bare rock. However, due to the practical challenges and cost of acquiring remotely sensed imagery at a sufficient resolution, these variables were not considered in the analysis.

Precipitous drops in ocean floor depth and steep slope gradients, such as isobaths or the mapped extent of the Continental Shelf have been used as modeling variables in seabird studies (Ainley et al. 1998; Nur et al. 2011). Isobaths and ocean topography were found to be highly associated with and exhibiting a causal relationship with GIS-detected thermal SST fronts (Valavanis et al. 2005). Birds often congregate at topographically defined 'hotspots' which are often associated with SST gradients (Nur et al. 2011). For this study, a proxy raster was generated to indicate areas where sharp drops in ocean floor depth could cause the formation of topographically-induced SST fronts or upwelling sites that could be attractive to seabirds. To accomplish this, a Python script was written which searched the GEBCO_08 raster for all locations where there was a bathymetry change of at least 500' (152.4m) between a central cell and any of its surrounding 8 cells. The identified pixels constitute what is herien referred to as 'bathymetric breaks' (Figure 1), which illustrates how the methodology can be used to identify known feeding grounds (Trimm 2004). Then using ArcMap, all the resulting bathymetric breaks that had a bottom depth of more than 750' (228.6m) were eliminated, a step performed to ensure that only near surface breaks were included in the analysis. These areas are likely to be associated with surface SST front formation and upwelling areas that affect surface conditions.

Methods 1.2: Method of analysis

Zonal division of the area of analysis.- Analysis of the area surrounding each presence or absence site was divided into two distinct zones: a Near Zone and a Pelagic Zone. The Near Zone constituted a circular area around each site with a radius of 50km. The Pelagic Zone was a ring that extended from 50km to 300km from the center of each site (Figure 2). Analysis of ocean properties within each is intended to ascertain whether or not the distance to food sources has a deterministic effect on the breeding distribution of Audubon's Shearwater. The outer limit of the Pelagic Zone is based on the approximate foraging radius of the closely related Manx Shearwaters (*Puffinus puffinus*) from Skomer Island in Wales during their nesting period (Guilford et al. 2008). Audubon's Shearwater and Manx Shearwater share a broadly similar breeding ecology (Brooke 1990).

Python scripts are used to derive a number of metrics to summarize conditions within each zone for each 'presence' and absence site. For SST, CHL and bathymetry, the following metrics were computed: minimum, maximum, mean, median, standard deviation, and mean absolute difference (MAD) as a metric of variability (Equation 1), where $\bar{x}$ is the mean value for each data set, x_i is each individual value of x, and n is the total number of data points.

Equation 1: $\frac{\sum_{i=1}^{n}|\bar{x}-x_i|}{n}$

For the bathymetric breaks data, the following metrics were calculated: number of bathymetric breaks per zone, total size of the breaks (in pixels), and the distance from each colony to the nearest break (minimum distance). Terrestrial slope and elevation were not analyzed by zone, though similar metrics to SST, CHL, and bathymetry were calculated for each of those variables. Since SST and CHL data have a temporal component, zonal analysis is only conducted on months during which birds are incubating (or are most likely be incubating for absence data) at a

given site. Once all the analyses had been performed, a Python script was run that averaged the data for the analyzed time span at each site, resulting in a single mean value.

Methods 1.3: Statistical Analysis

Identifying statistically significant variables.- Using a combination of Minitab 16 (Minitab Inc., 2013) and the SciPy module of Python (SciPy.org, 2014), means or medians of the 'presence' and 'absence' data were compared using two-sampled t-tests or Mann-Whitney U Tests. Variables with means (or medians) that are statistically significantly different between the two groups were selected for use in the logistic regression model.

Selection of variables for logistic regression.- Multivariate binomial logistic regression from the Generalized Linear Model set of equations is a robust method of analysis and is often used in modeling presence and absence data (Huettmann and Diamond 2001; Loiselle et al. 2003). The logistic regression approach employed in this study is implemented using RStudio (RStudio, 2013). Initially, for each zone a total of seven variable metrics were selected and added to the regression equation for subsequent analysis. Results of the model were analyzed using the methodology of Barve and Slocum (2014). The code sorts predicted values into a contingency table based on whether or not the probability that the dependent variable is equal to 1 was greater or less than a cutoff of 0.5 (generating a predicted presence or absence) and comparing them to the actual presence and absence values of the dependent variable. Variables are subtracted and added until a model is reached that maximizes correct predictions while minimizing Type-I and Type-II errors (false-positives and false-negatives, respectively).

Sensitivity analysis.- The initial logistic regression analysis uses a cutoff probability value of 0.5 to construct the contingency tables showing the accuracy of the model. A sensitivity

analysis was conducted by running the same code with different cutoff values, from 0.25 to 0.75. The total number of actual predicted presences and actual predicted absences are each plotted as a percentage of the total number of presences and absences, resulting in two data sets. Linear regression was conducted on each data set, and the '*x*' value of the intersection of the two equations was calculated. This value '*x*' represents the approximate cutoff probability value where the columns of the contingency table add up to the original number of presences and absences while maximizing the ability of the model to correctly predict values. An optimized sensitivity probability was obtained for each zone using this method.

Accuracy analysis by geographic region.- The accuracies for the logistic regression equations for each zone were also calculated based on the two main geographic regions in the Caribbean: the Greater Antilles and Lesser Antilles. Using ArcMap, the main spatial data file containing the results of the logistic regression analyses and their predictions was divided into these two regions. Using these geographically divided data files, regional model accuracies were calculated based on contingency tables that sorted correct versus incorrect predictions.

Model validation.- Cross-validation with replication was performed on the Near Zone logistic regression model as a standard form of model validation (Mertler and Vannatta 2013). A random subset of five presence sites and five absence sites was removed from the model and the logistic regression was re-run with the remaining data. The resulting equation was then used to calculate the probabilities for the ten removed sites. Using the optimized probability derived from the sensitivity analysis as a cutoff, the ten sites were sorted into correct or incorrect predictions. The predicative accuracy was then calculated for the ten sites as a percentage. This procedure was repeated 25 times. To test whether the cross-validation results deviated from the

overall model accuracy, a one-sample t-test was performed, testing the group mean against the overall model accuracy.

Methods 1.4: Puffinus l. loyemilleri analysis

Analysis set-up.- GIS data file was constructed of nine sites where *P. l. loyemilleri* could be potentially breeding using information gathered from multiple sources, including A. J. Delnevo, (*personal communication*), Bradley and Norton (2009), and Croxall et al. (1984). The sites were selected based on how recently they had been surveyed (if at all), their proximity to known or former breeding sites for *P. l. loyemilleri*, and the suitability of the habitat. Using the methodology set out in the earlier sections of this paper, the Near and Pelagic Zone analyses were run on all nine sites. The resulting data were then entered into the Near and Pelagic Zone logistic regression equations. The probabilities were then sorted as predicted presences and absences, and then the sites were ranked based on whether both were predicted as a presence, if only one zone predicted a presence, or if both predicted an absence. Within these categories, the results were ranked by averaging the actual probabilities generated by the logistic regression equations.

Results

Statistically significant variables.- Of the four oceanographic variables tested (SST, CHL, bathymetry, and bathymetric breaks), at least one metric for each variable showed statistical significance at an alpha level of 0.05 (Table 1). For the Near Zone, the variables and metrics that showed statistical significance were Bathymetric Mean and Median, CHL Maximum and Standard Deviation, SST Maximum, Number of Bathymetric Breaks, and Size of Bathymetric Breaks. For the Pelagic Zone of analysis, Bathymetric Mean, Median, and Standard Deviation, CHL Maximum, and SST Maximum were statistically significant. The Minimum Distance from a bathymetric break to a site is zone independent and also reported the highest level of statistical significance, with p-value=0.00034, and a difference in the medians of the two groups of 0.077 angular degrees (approximately 8500m at the equator). A comparison between the means (or medians) of the remaining presence and absence groups for the variables and metrics tested is also related in Table 1. There were no statistically significant metrics for the terrestrial variables (results not shown).

Selection of variables for logistic regression.- Due to the Near Zone presenting a larger number of variables that were statistically significant, the variables selected for logistic regression came from a subset of those variables. From the variable of bathymetric depth, the metric of Mean Bathymetry was chosen due to its lower p-value than Bathymetric Median. The single metric of CHL Maximum was selected, as it was the only metric of CHL that showed statistical significance. From SST, the Maximum and Mean metrics were selected. Mean SST was selected despite a non-significant (though low) p-value, due to inclusion of multiple SST

metrics in some studies (for example Huettmann and Diamond 2001). All three metrics for bathymetric breaks were also included, for a total of four variables and seven metrics.

Multivariate logistic regression results.- The Near Zone logistic regression analysis yielded an equation with four different variables (Table 2): Bathymetric Mean, SST Maximum, Size of Bathymetric Breaks, and Minimum Distance to Bathymetric Breaks. Results of the sensitivity analysis indicated a probability cutoff of 0.54, and actual manipulation showed that a probability value of 0.53 yielded a model that had the greatest predicative accuracy for the Near Zone (Table 3). The model was able to predict 62 presences and 44 absences correctly, for a model accuracy of 62.72%. The results of the Near Zone analysis have been visualized in Figures 3 through 5.

Results for the Pelagic Zone logistic regression analysis also yielded a four-variable equation (Table 4). Variables that provided the best predicative model were SST Maximum, SST Mean, Size of Bathymetric Breaks, and Minimum Distance to Bathymetric Breaks. The sensitivity analysis provided a probability cutoff value of 0.56, which resulted in contingency table with the highest predicative accuracy for the Pelagic Zone (Table 5). The model predicted 63 presences and 43 absences correctly, for a model accuracy of 62.72%. Results of the Pelagic Zone are mapped in Figures 6 and 7.

In an attempt to discern any geographic patterns that might indicate where the models differ in their predicative results, Figure 8 maps the predicted results of the two zones against each other. One pattern that does emerge is that in the Greater Antilles, where the models generated for both zones yield predicted results that are very similar, particularly in the Bahamas. However, within the Lesser Antilles, the predictions of the two models differ considerably. Table

6 provides a contingency table to demonstrate how accurately each model performed with respect to the other: the predictions of the two models coincided 81.07% of the time. Geographically, in the Greater Antilles, the models coincided 82.17% of the time, while in the Lesser Antilles they coincided 72.05% of the time. The accuracy of the two models was also greater on average in the Greater Antilles, with the Near Zone model performing with an accuracy of 68.31% and the Pelagic Zone performing with an accuracy of 65.34%. In the Lesser Antilles, the Near Zone model showed an accuracy of 52.94% while the Pelagic Zone model demonstrated an accuracy of 58.82%.

Model validation results.- The results of the replicated cross-validation of the Near Zone logistic model did not differ statistically from the overall model accuracy of 62.72%. A one-sample t-test performed on the pooled results of 25 replicates compared the mean of the group to the overall model accuracy of 62.72%. The pooled results had a mean of 59.20% ±17.54% with t=-1.00, df=24, p=0.326. The logistic regression model appears to be fairly robust when subjected to cross-validation.

Puffinus l. loyemilleri analysis results.- Of the nine potential breeding sites for *P. l. loyemilleri*, three were predicted to be suitable by the statistical analysis conducted in this study. Of the three, Las Tortuguillas were predicted to be presences by both the Near and Pelagic Zone logistic regression equations using the optimized probability values as the cut-offs. Of the remaining two sites, Bubies Bajo, on the La Roques island chain was predicted by the Pelagic Zone equation as a presence with a probability of approximately 65.5%. Klein Curaçao was predicted by the Near Zone to be a presence with a probability of approximately 55.7%. Of the remaining the sites, the probabilities were averaged and used as a metric to rank the islands in order of likelihood that the *loyemilleri* subspecies breeds there. Logistic regression probabilities

are an ideal metric for this, as the value is actually the probability that outcome is “1” or a presence. Islote Sucre off Northern Columbia had the highest mean probability of the remaining sites, nearing 50%, while Monjes del Sur from the Los Monjes island group off the Columbian/Venezuelan border had the lowest probability of approximately 15%. Full results of the analysis of potential breeding sites for *P. l. loyemilleri* are depicted in Table 7. A map of the resulting predictions is given in Figure 9.

Discussion

Discussion 1.1: Pre-laying Exodus

Nesting locations for Audubon's Shearwater were analyzed throughout the Caribbean in order to determine which factors likely contribute most to their breeding site distribution. The measured variables were then used in logistic regression in order to determine exactly which subset worked together to create the best predicative model, and to determine which zone of analysis would do a better job of predicting this distribution. Results of the logistic regression indicated a similar, though not exact subset of variables driving the breeding distribution in each zone, and an equal predicative accuracy. However, the Near Zone had a total of seven different statistically significant variable metrics, including one variable that was significant only for that zone, compared to five variable metrics of the Pelagic Zone. This suggests that the Near Zone likely has a slightly greater role in determining the breeding distribution of Audubon's Shearwater than the Pelagic Zone. This conclusion is reflected in the biology of the birds and what these two zones could potentially be representing in terms of the breeding ecology of Audubon's Shearwater.

As of Bull's (2006) work on the pre-laying exoduses of shearwater species, no new information pertaining to the role of Audubon's Shearwaters in this phenomenon had been discovered to fill the gaps in of what was published by Warham (1990). However, in the ecologically closely-related Manx Shearwater, there have been reports that only the females undergo the exodus, while the males and non-breeders stay on the colony (Perrins and Brooke 1976; Warham 1990). Harris (1966) suggested that both sexes left the nesting colonies, but was

unable to comment on their movements after leaving their colony. If Audubon's Shearwaters display a similar pattern in pre-laying exodus ecology to Manx Shearwater as reported by Warham (1990), the results of the zonal pattern of analysis could be explained by the two different sexes operating in the two different zones.

Female birds on the pre-laying exodus could be using the Pelagic Zone (or possibly greater distances) to search for food in order to gain sufficient nutrients for egg (particularly yolk) development and thereby positively influence breeding success through egg size (Birkhead and Delnevo 1987; Birkhead and Nettleship 1984; Delnevo 1990; Warham 1990). Studies of other seabirds have shown that females may be avoiding nesting colonies to minimize forced extra-pair copulations (EPC's) (Birkhead et al. 1985; Birkhead and Delnevo 1987). Whereas males likely stay close to shore, using the Near Zone for daily foraging in order defend their nest site, be present to copulate with their returning female, and obtain EPC's with visiting females (Birkhead et al. 1985, Birkhead and Delnevo 1987, Delnevo 1990).

A similar nest guarding behavioral pattern of the males was observed in another shearwater species, the Pintado Petrel (*Daption capensis*) (Pinder 1966). If the males are constrained to stay close to shore to visit and guard the nests, while the females can range longer distances, it would offer a possible explanation why a male-driven Near Zone appears to be more important. This is supported by looking at the greater number of variables that are statistically significant in the Near Zone when compared to the Pelagic Zone. However, because the tasks of both the male and female are important, each zone of analysis can be used effectively as a predicative model via logistic regression. The two equations likely describe different oceanic ecosystems, both of which deal with variables that are important to the birds' prey concentration (Nur et al. 2011; Reese et al. 2011; Vilchis et al. 2006). Despite the temporal analysis not being

conducted in concert with the pre-laying exodus period, the conclusions drawn here are not invalid. It is likely that the signal shown by SST in this study is similar but weaker than it would have been had it been analyzed during the pre-laying exodus period.

Discussion 1.2: Sources of Error and Potential Changes in Methodology

After probability value optimization, both models showed a predicative accuracy of 62.72%, with only a slight difference in the predicted presences and absences compared to the actual presence and absences (Tables 3 and 5). One potential source of experiment error is that the absence data in this study were not 'true' absence data according to its definition in niche modeling (Peterson et al. 2011). Data used in this study could contain artificial absences, in that Audubon's Shearwaters are actually present in the absence sites, but were not detected during seabird surveys on the islands, a problem that affects the accuracy of predicative models (Anderson 2003). This phenomenon could be reflected by the relatively high Type-1 error rate in the two predicative models: 18.3% for the Near Zone and 18.9% for the Pelagic Zone.

A further problem is that the 'absences' used in this study constituted a non-random subset of the total available dataset. This was done due to difficulty of selecting sites that had a higher likelihood of not harboring Audubon's Shearwater. Had all the potential 'absences' in Bradley and Norton (2009) been included, it would have created an absence to presence ratio of nearly 7:1. Conversely, Bonn and Schröder (2001) indicated that the prevalence of presences in a logistic regression dataset should be between 20-80%. A balanced dataset was therefore ideal, but there was no obvious way to create a dataset that would be balanced and high-quality and still random. Bradley and Norton (2009) did not indicate sites where multiple surveys had been conducted. Had this information been available, it would have been used as the criteria for

generating the subset of 'absence' data, as sites that had been surveyed multiple times with no shearwater detection would have minimized the likelihood of false absences, and therefore had been ideal candidates for analysis. Not detecting nesting Audubon's Shearwater during regular seabird surveys is more probable due to their nocturnal nesting behavior (Mackin 2004).

Future research in this area should focus on determining the dynamics of the pre-laying exodus of Audubon's Shearwaters, particularly in regards to where birds from different areas of the Caribbean go during this period. This could be done through the use of GPS tracking, which was successfully utilized by Guilford et al. (2008) to track foraging patterns of Manx Shearwater. Knowing exactly where the females go would allow for a targeted analysis of the proper geographic region(s) responsible for supplying the food, and therefore the energy necessary to form their individual egg. A logistic regression analysis using variables from known foraging areas may provide greater insight into the females' role in the determining the breeding distribution. The temporal analysis should be changed to reflect the several week long pre-laying exodus period rather than the incubation period (Warham 1990).

Other improvements in methodology could include the use of better proxies for SST fronts than were available. Oceanographic currents, such as the California Current (the Gulf Stream is a Caribbean counterpart), also play a large role in seabird dynamics (Ainley et al. 2005; Nur et al. 2011). Even the simplest models are confounded by variables such as coastal tides and winds (Gaston 2004). Using the theory behind oceanic barotropic flow, it could be possible to model currents in a manner more in keeping with the actual dynamics inherent in physical oceanography (Gille et al. 2004). However, attempts to model barotropic flow using ArcMap proved unsuccessful, possibly due to the unsuitability of GIS as an oceanographic modeling platform (S. Gille, *personal communication*).

A final comment on the methodology used in this paper involves the averaging of the SST data for multiple years. Sea surface temperatures are dynamic systems that show significant inter-annual and longer term variability. For example cyclical patterns such as the El Niño effect in the Pacific are known to affect breeding seabirds and many other species (Castillo-Guerrero et al. 2011). By averaging the temporal data, annual variation is removed, resulting in an inherent loss of information on how dynamic SSTs impact Audubon's Shearwater populations. If dates of nesting were more carefully marked and dated, a study like this one would be markedly improved, but given the constraints of the observational data this study has to be limited to evaluating mean conditions as the underlying information source. A consequence of this decision is that it is impossible to make an assessment of how frequently specific locations might be used as nesting sites, and that there may be locations that are used in some years but not others. This uncertainty should be considered when making future observations of Audubon's Shearwaters nesting sites and presence/absence statistics.

Discussion 1.3: Puffinus l. loyemilleri Analysis

To test its practical applications, the methodology of this study was applied to the geographic area off the coast of Venezuela and Columbia, where the *loyemilleri* subspecies of Audubon's Shearwater breeds and is close to extinction (Balloffet et al. 2006; Croxall et al. 1984; Howell 2012). Results of the analysis were encouraging, in that logistic regression equations from the two zones predicted that three out of the nine sites analyzed would be suitable for the *loyemilleri* subspecies. The island predicted by both equations, Las Tortuguillas off Venezuela's La Tortuga has not been surveyed for Audubon's Shearwater according to Bradley and Norton (2009). Bubies Bajo, which was predicted by the Pelagic Zone, is part of the La Roques island group, which has several other islands that have confirmed breeding of the

loyemilleri subspecies. This suggests that most, if not all the islands in this group could likely harbor the subspecies. Klein Curaçao, which was predicted as a presence by the Near Zone, was surveyed in 2002 (Bradley and Norton 2009), but only the Cayenne Tern was found. This species breeds at a different time than Audubon's Shearwater at this latitude (A. J. Delnevo, *personal communication*; Dinsmore 1972). This could mean that Audubon's Shearwaters are in fact nesting here, and a survey for this species specifically is needed.

Other results of interest include the high mean probability for Islote Sucre off Columbia's San Andrés Island. There was a colony of *P. l. loyemilleri* on the island of Providéncia directly to the north of San Andrés which has since become extirpated (Croxall et al. 1984). It may be that on the small cay of Islote Sucre there still exists a population of the birds. Conversely, the incredibly low probability prediction from both zones for Monjes del Sur from the Los Monjes island group indicates that no survey should be necessary, as the likelihood of Audubon's Shearwaters nesting on this islands chain off a peninsula of Columbia west of Aruba is extremely low. Richmond Island off Tobago was ranked 5th in the results of the analysis and had a probability similar to the known sites for *loyemilleri* that breed in large numbers off Tobago. This indicates that while the colony was not predicted as a presence by the model, it may still warrant a survey for Audubon's Shearwater if one has not been conducted (Bradley and Norton [2009] made no mention of one). The promising results of the application of this study's methodology to *P. l. loyemilleri* provides a practical example of how this study can be used to direct conservation efforts of the species in Caribbean region.

Discussion 1.4: Use of the Study in General Conservation

The finding from this study can be applied to the entire region, or on an island-by-island basis, using the resulting calculated probabilities to determine whether or not the island is likely to be home to nesting shearwaters. When considering which model to use from a geographic perspective, both models could be used with equal efficacy in the Greater Antilles, particularly within the Bahamas. Within the Lesser Antilles, the Pelagic Zone model performs noticeably better than the Near Zone and may prove to be more useful for locating unidentified Audubon's Shearwater breeding sites.

Loiselle et al. (2003) suggested that minimizing Type-I error is ideal from a conservation standpoint as it reduces the conservation of land where the species is not actually found. The solution presented in this research of minimizing both types of error by optimizing the probability cutoff value appears to be ideal from a conservation standpoint The Audubon's shearwater population is considered to be declining throughout the Caribbean (USFWS 2011), and the species has been placed on the American Bird Conservancy's 'Watch List' (ABC 2007). Threats to Audubon's Shearwater include introduced cats and rats within the nesting grounds, over-fishing of their prey, accidental capture in fishing gear, and collisions with man-made structures at sea (USFWS 2011, ABC 2007). This study will aid the identification of the factors that influence the nesting distribution of the species and will thereby contribute to a comprehensive conservation management plan for this species.

Conclusion

Conclusion 1.1: Research in Retrospect

If a more thorough literature review been conducted upon the initiation of this research project, the likely underlying mechanism for the breeding distribution of Audubon's Shearwater; the pre-laying exodus, would have been recognized earlier. Had this occurred, the nature of the analysis and how it was carried out would have been changed to reflect this realization (to the extent possible given the existing knowledge). Little is known about the spatial distribution of shearwater species during the pre-laying exodus, and nothing for Audubon's Shearwater. However, Manx Shearwaters were found to have traveled at least 820km during this period (Perrins and Brooke 1976). The ecological setting in which that Perrins and Brooke (1976) performed their study is very different from the Caribbean: the study occurred by tracking birds from Wales to the Bay of Biscay, which is a cold water region, rather than a tropical one. Due to the different ecologies of the two regions, a proper basis for scaling the distance of the Pelagic Zone cannot be accurately determined. For the purposes of this study, a large increase in this distance would have resulted in a significant degree of data overlap in the analysis, which could have caused significant statistical problems.

The temporal analysis, which was a key factor when conducting the analysis of SST and CHL, would have undergone a significant change. Rather than focusing on the incubation period of Audubon's Shearwater, which was initially hypothesized to be the key period of interest, the analysis would have been centered on the several-week long period during which Audubon's Shearwaters perform the pre-laying exodus. The exact length of this period is unknown, but, if the species follows the similar Manx Shearwater, it is likely to be between 14 and 21 days (Bull

2006). The temporal analysis should therefore have been altered to analyze the month directly prior to the incubation periods documented for the presence and absence sites. This would have likely yielded a stronger signal for the SST metrics in the logistic regression analysis and perhaps improved the overall model accuracy. It is unlikely to have altered the variables or metrics included in the regression model.

Other improvements in the methodology could have included the addition of threats to Audubon's Shearwaters as terrestrial variables. On many of the larger islands in the Caribbean there is a significant human presence, while many of the small cays remain uninhabited. Audubon's Shearwaters have a documented pattern of mortality in association with anthropomorphic light sources (Le Corre et al. 2002), and as such, the presence of humans on islands could have a role in deterring whether or not nesting occurs. It is probable that any human impact would be on the number of birds nesting rather than a presence/absence dynamic: large colonies of Audubon's Shearwaters exist on heavily populated islands, such as Saba in the Netherlands Antilles and Réunion Island in the Indian Ocean (A. J. Delnevo, *unpublished data*; Brentagnolle et al. 2000; Le Corre et al. 2002). Other threats to Audubon's Shearwaters, such as rats, likely exist on virtually every island and cay in the Caribbean and as such would not be a good variable to include (A. J. Delnevo, *personal communication*). The presence or absence of other predators, such as feral cats, may have proven significant, however, these data were unavailable for all the requisite presence and absence sites.

Conclusion 1.2: Future Research

Results of this study open the doors to a myriad of other research opportunities and projects. One such line of research is to work to further identify the respective roles of males and

females in determining the breeding distribution of Audubon's Shearwater. A second line of inquiry is to use the existing model to identify breeding sites for the endangered *P. l. loyemilleri* subspecies both within and around the Caribbean, (of which an exploratory attempt has been made in the course of this manuscript). A third avenue of research suggested by this study is to focus on the spatial distribution of females undergoing the pre-laying exodus, as this information would have been invaluable in conducting the initial research.

In order to investigate the roles of males and females in the driving the breeding distribution of Audubon's Shearwaters, the results of this study could be combined with nesting success data for individual shearwater colonies. If enough nesting success data were obtained, a series of advanced statistical analyses could be run to both test whether or not the zone of analysis has an effect on nesting success, and which model has a better fit when regressing either the oceanic variables themselves or the predicted probabilities against the nesting success. If the zone of analysis proved to be the significant factor, then a judgment call could be made as to which zone's regression equation fit the data better.

If a linear regression equation relating predicted nesting probabilities of the Near Zone to nesting success at a given year had a higher R^2 value when compared to the R^2 of an equivalent equation for the Pelagic Zone, it could be interpreted that the Near Zone, and therefore males were more important in determining the nesting success of a colony. This could then allow some inferences to be made as to whether or not the males were more important in selecting overall nest sites if their influence in nesting success was higher than that of the females. This particular study may not be possible for Audubon's Shearwater due to the lack of data on nesting success for large numbers of colonies and large numbers of years. However, because the methodology and scripts are already written, a similar analysis for Manx Shearwater, for which the nesting

success data likely exists, could easily be conducted. Similarly, a well-studied tropical shearwater species could be used, for which the existing logistic model could likely be transferable.

A second potential project involves applying the current model to an endangered subspecies of Audubon's Shearwater. In the Caribbean region, the subspecies *P. l. loyemilleri* only occurs off Northern Venezuela. On the Pacific side of the Central American isthmus, it also occurs off Panama, where it is close to extinction (Balloffet et al. 2006; Howell 2012). Lopes et al. (2014) identified breeding habitat for this subspecies off the coast of Brazil, where it is on the Brazilian Red List of threatened species. Due to the relatively low Type-I error of this model, the logistic model developed in this research could perform well for conservation work according to the criteria set forth by Loiselle et al. (2003).

The identification and protection of habitat for threatened and endangered species is of paramount concern in the conservation world. The use of the predicative models created by this study could be helpful to identify potential breeding habitat for this subspecies to be targeted for conservation. In this way it may be possible to preserve or even expand the remaining populations of *P. l. loyemilleri*. Further knowledge of its distribution might allow for a more detailed study of this subspecies, which is still poorly known both ecologically and otherwise (Howell 2012).

In this thesis, an exploratory foray into this avenue of research was conducted with promising results. Before continuing this type of analysis, the most promising islands identified during the *Puffinus l. loyemilleri* section of this thesis; Las Tortuguillas, Bubies Bajo, and Klein Curaçao, should be surveyed manually for this subspecies. Successfully locating breeding

colonies on any of these three islands, especially the first and last, would both validate the methodology and indicate whether or not a much more in-depth analysis of this part of the Caribbean is warranted.

A significant shortcoming in the current methodology of this paper is the nature of the Pelagic Zone. While the males of Audubon's Shearwaters, if they follow the pre-laying exodus pattern of Manx Shearwater set out by Warham (1990), likely stay in what is approximately the Near Zone, the females could be a different matter. Manx Shearwaters have a maximum flight range of up to 700 miles (1150km) per day (Perrins and Brooke 1976). While evidence from Guilford et al. (2008) suggests that during incubation they don't stray more than approximately 300km from their nesting sites, it is possible that during the pre-laying exodus they travel much further. In one study, evidence indicates that at least some Manx Shearwaters traveled up to 820km from Skokholm, and Dyfed Island off Wales to the Bay of Biscay during this period (Perrins and Brooke 1976). Therefore, to have a more informed notion of the spatial distribution of females during this period, more knowledge is needed of their location during pre-laying exodus.

A methodology that combines that of Guilford et al. (2008) with Perrins and Brooke (1976) is a possible approach for this line of research. This would use GPS trackers to monitor Audubon's Shearwater females captured at nesting sites during copulation and tracking their movements during the pre-laying exodus to ascertain their movements. Of the possible sites that could be surveyed, the most promising options from which Audubon's Shearwaters could be collected are from either the San Salvador, Bahamas colony studied by Trimm (2004) or the Long Cay colony in the Exumas studied by Mackin (2004), as both are easily accessible and have large numbers of nesting birds. A study of this kind would also help illuminate exactly what

kind of marine feature Audubon's Shearwaters are drawn to during this period (for example, cold water upwelling areas or warm-water stationary fronts). This would allow for a considerable narrowing of variables used in future logistic regression models, likely increasing their predicative accuracy substantially. To do so would require that the conditions could be accurately re-created using GIS or ocean circulation models more suited to simulating oceanographic features and conditions. The possibilities opened up by this research are numerous and have the potential to greatly increase what is known about Audubon's Shearwaters or any other shearwater species to which the methodology is applied.

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Appendix A: Tables

Table 1. Statistical results for oceanographic variables

Oceanographic Variables										
Variable	**Measurement**	**Minimum**	**Maximum**	**Mean**	**Median**	**MAD**	**SD**	**Minimum Distance**	**Number of Breaks**	**Size of Area**
Bathymetry Near	**P-value**	0.142	NA	**0.01***	**0.017**	NA	0.08	NA	NA	NA
	Presence Mean	-3562	NA	**-1360**	**-1188**	NA	1025	NA	NA	NA
	Absence Mean	-3235	NA	**-1019**	**-763**	NA	912	NA	NA	NA
Bathymetry Pelagic	**P-value**	0.371	NA	**0.013**	**0.012**	NA	**0.044**	NA	NA	NA
	Presence Mean	-6566	NA	**-2769**	**-2864**	NA	**1983**	NA	NA	NA
	Absence Mean	-6359	NA	**-2392**	**-2280**	NA	**1849**	NA	NA	NA
Chlorophyll-a Near	**P-value**	0.1951	**0.0111**	0.2224	0.34914	0.07385	**0.0223**	NA	NA	NA
	Presence Median	0.07591	**0.3831**	0.164	0.10147	0.0444	**0.0682**	NA	NA	NA
	Absence Median	0.07701	**0.6401**	0.1562	1.0642	0.0617	**0.1008**	NA	NA	NA
Chlorophyll-a Pelagic	**P-value**	0.1559	**0.3521**	0.4931	0.3861	0.47666	0.18399	NA	NA	NA
	Presence Median	0.04484	**4.402**	0.16926	0.0844	0.1752	0.423	NA	NA	NA
	Absence Median	0.04506	**4.829**	0.14627	0.08173	0.1117	0.4543	NA	NA	NA
SST Near	**P-value**	0.18	**0.008***	0.067	0.069	0.311	0.129	NA	NA	NA
	Presence Mean	26.019	**26.96**	26.342	26.315	0.159	0.201	NA	NA	NA
	Absence Mean	26.209	**27.378**	26.571	26.542	0.177	0.239	NA	NA	NA
SST Pelagic	**P-value**	0.472	**0.004***	0.087	0.114	0.877	0.804	NA	NA	NA
	Presence Mean	25.01	**29.03**	26.293	26.32	0.433	0.525	NA	NA	NA
	Absence Mean	25.14	**29.54**	26.503	26.515	0.429	0.533	NA	NA	NA
Bathymetry Breaks Near	**P-value**	NA	NA	NA	NA	NA	NA	NA	**0.005***	**0.0033***
	Presence Median	NA	NA	NA	NA	NA	NA	NA	**8**	**971.5**
	Absence Median	NA	NA	NA	NA	NA	NA	NA	**5**	**589**
Bathymetry Breaks Pelagic	**P-value**	NA	NA	NA	NA	NA	NA	NA	0.061	0.286
	Presence Median	NA	NA	NA	NA	NA	NA	NA	109.1	17650
	Absence Median	NA	NA	NA	NA	NA	NA	NA	97.1	16355
Bathymetry Breaks	**P-value**	NA	NA	NA	NA	NA	NA	**0.00034***	NA	NA
	Presence Median	NA	NA	NA	NA	NA	NA	**0.1097**	NA	NA
	Absence Median	NA	NA	NA	NA	NA	NA	**0.1867**	NA	NA

This table reports the results of the comparison of means (or median) tests comparing the data from the presence and absence groups. The p-value of the test and their measures of central tendency for both the presence and absence groups are presented as well. All tests were conducted using a two-sampled t-test with df=167, unless 'median' is specified, in which case a Mann-Whitney U Test was performed. Data in bold font represent tests with a p-value significant at a α=0.05, a * indicates the test was significant for α=0.01. Bathymetric data are in feet, and MODIS/AQUA SST and Chlorophyll-a data is in ˚C and mg/m^3 (respectively). The Bathymetric Break metric of Minimum Distance is in angular degrees, the other two metrics for this variable are unit-less.

Table 2. Near Zone logistic regression results

Near Zone Logistic Regression Coefficients			
Variable	**Coefficient**	**P-value**	**AIC**
Intercept	12.120123	**0.0112**	222.75
Bathymetric Mean	-0.0000436	0.8572	
Temperature Maximum	-0.4457084	**0.0103**	
Size of Bathymetric Break	0.0002741	**0.0397**	
Minimum Distance to Break	-0.7508229	0.2834	

This table relates the coefficients for the multivariate logistic regression equation for the Near Zone of analysis with their associated p-values. Bold font indicates a p-value that was statistically significant at an $\alpha=0.05$. (AIC=Akaike Information Criterion value associated with the equation.)

Table 3: Contingency table for the Near Zone optimized logistic regression model

Near Zone Logistic Regression Model		
	Predicted Absences	**Predicted Presences**
Actual Absences	44	31
Actual Presences	32	62

This contingency table represents the number of correctly predicted presences and absences to the number of false-positives and false-absences (representing Type-I and Type-II errors, respectively). The probability cutoff value for this model was calculated to be 0.544 and fixed at 0.53. Overall 62 presences and 44 absences were correctly predicted out of 169 total sites, for a model accuracy of 62.72%.

Table 4. Pelagic Zone Logistic Regression Results

Best Predicting Model With Changes			
Variable	**Estimate**	**P-value**	**AIC**
Intercept	32.58	**0.00171****	220.64
Temperature Mean	-0.6227	**0.03138****	
Temperature Maximum	-0.5407	**0.00277****	
Size of Bathymetric Break Area	0.00001295	0.63772	
Minimum Distance to Break	-1.259	0.0542	

This table relates the coefficients for the multivariate logistic regression equation for the Pelagic Zone of analysis with their associated p-values. Bold font indicates a p-value that was statistically significant at an α=0.05, and an * indicates a p-value that is significant at an α=0.01.

Table 5. Contingency table for the Pelagic Zone optimized logistic regression model

Pelagic Zone Logistic Regression Model		
	Predicted Absences	**Predicted Presences**
Actual Absences	43	32
Actual Presences	31	63

This contingency table represents the number of correctly predicted presences and absences to the number of false-positives and false-absences. The probability cutoff value for this model was calculated to be 0.56. Overall 63 presences and 43 absences were correctly predicted out of 169 total sites, for a model accuracy of 62.72%.

Table 6. Table comparing the Near and Pelagic Zone's predictions.

Comparison of Probability Predictions		
	Predicted Absence Pelagic	Predicted Presence Pelagic
Predicted Absence Near	61	15
Predicted Presence Near	17	76

This contingency table compares the predicted values for the Near and Pelagic Zone regression models. The models agreed 81.07% of the time.

Table 7. *Puffinus l. loyemilleri* Analysis

Puffinus l. loyemilleri Analysis Results						
Name	Rank	Near Zone Probabilities	Pelagic Zone Probabilities	Near Prediction	Pelagic Prediction	Mean Probability
Las Tortuguillas	1	0.616831855	0.677966982	1	1	0.64739942
Bubies Bajo	2	0.443174100	0.655356121	0	1	0.54926511
Klein Curacao	3	0.557206838	0.106042388	1	0	0.33162461
Islote Sucre	4	0.453308395	0.537400736	0	0	0.49535457
Richmond Island	5	0.465830037	0.219631194	0	0	0.34273062
Puerto Real	6	0.411088343	0.132688937	0	0	0.27188864
Isla la Sola	7	0.390784063	0.144042433	0	0	0.26741325
Isla de Patos	8	0.249369090	0.106204108	0	0	0.17778660
Monjes del Sur	9	0.280665122	0.018489911	0	0	0.14957752

This table shows the results of the analysis of unsurveyed (or if surveyed, not for this species) sites for the subspecies endangered subspecies of Audubon's Shearwater *P. l. loyemilleri.* The results are ranked in order of the interest of the island to future survey teams based on whether or not it was predicted as being a presence site, and then by the average logistic regression value. This value is actually the direct probability that a site is a presence, thereby rendering it the most logical metric for assessing which islands are most suitable.

Appendix B: Figures in Paper

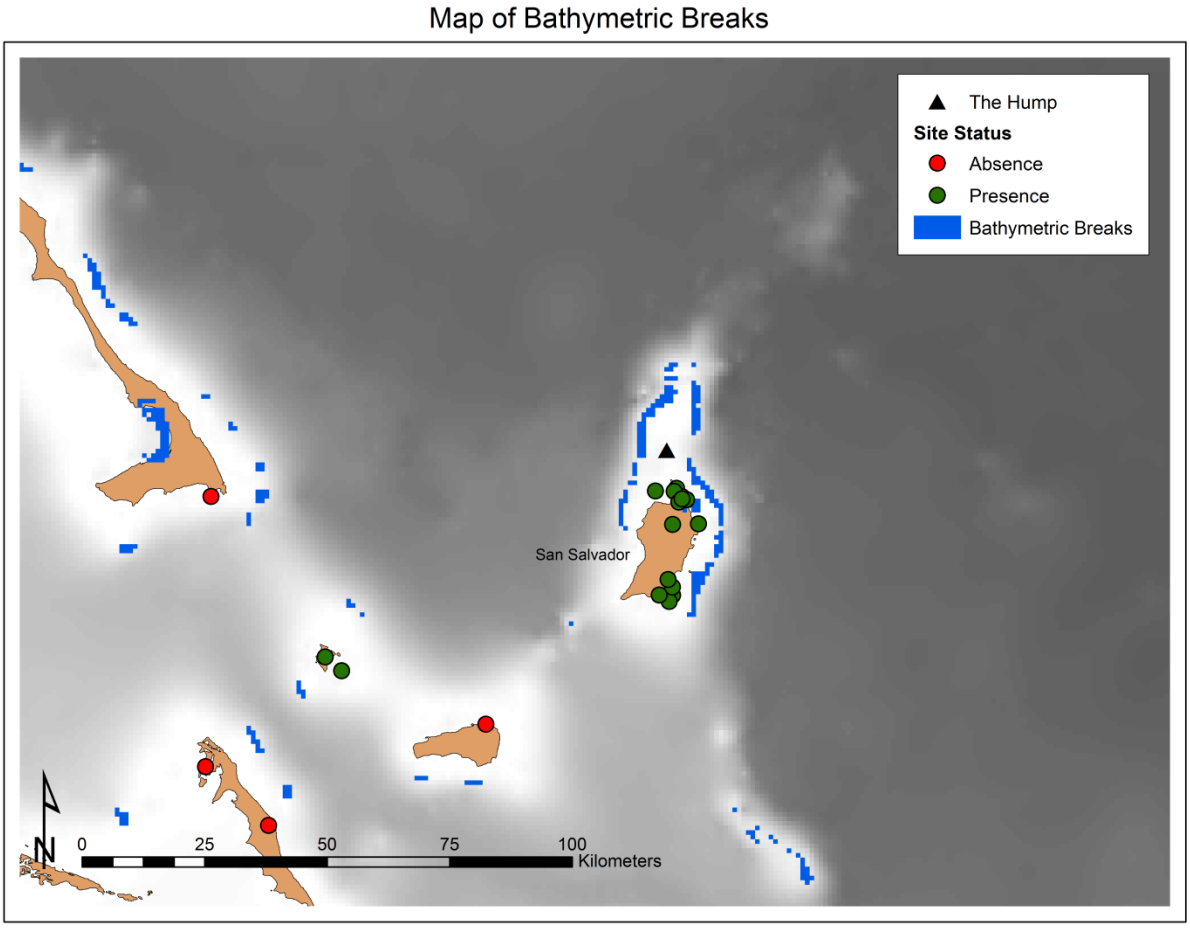

Figure 1. Map of Bathymetric Breaks. This figure illustrates the results of the procedure for generating 'bathymetric breaks' used in this paper. By focusing on San Salvador, the method can also be seen to identify the outline of the presence of a feature Trimm (2004) referred to as 'The Hump'; a sub-surface topographic feature that Audubon's Shearwaters would often travel to in order to feed. This demonstrates the ability of this methodology to identify important documented feeding grounds for Audubon's Shearwaters.

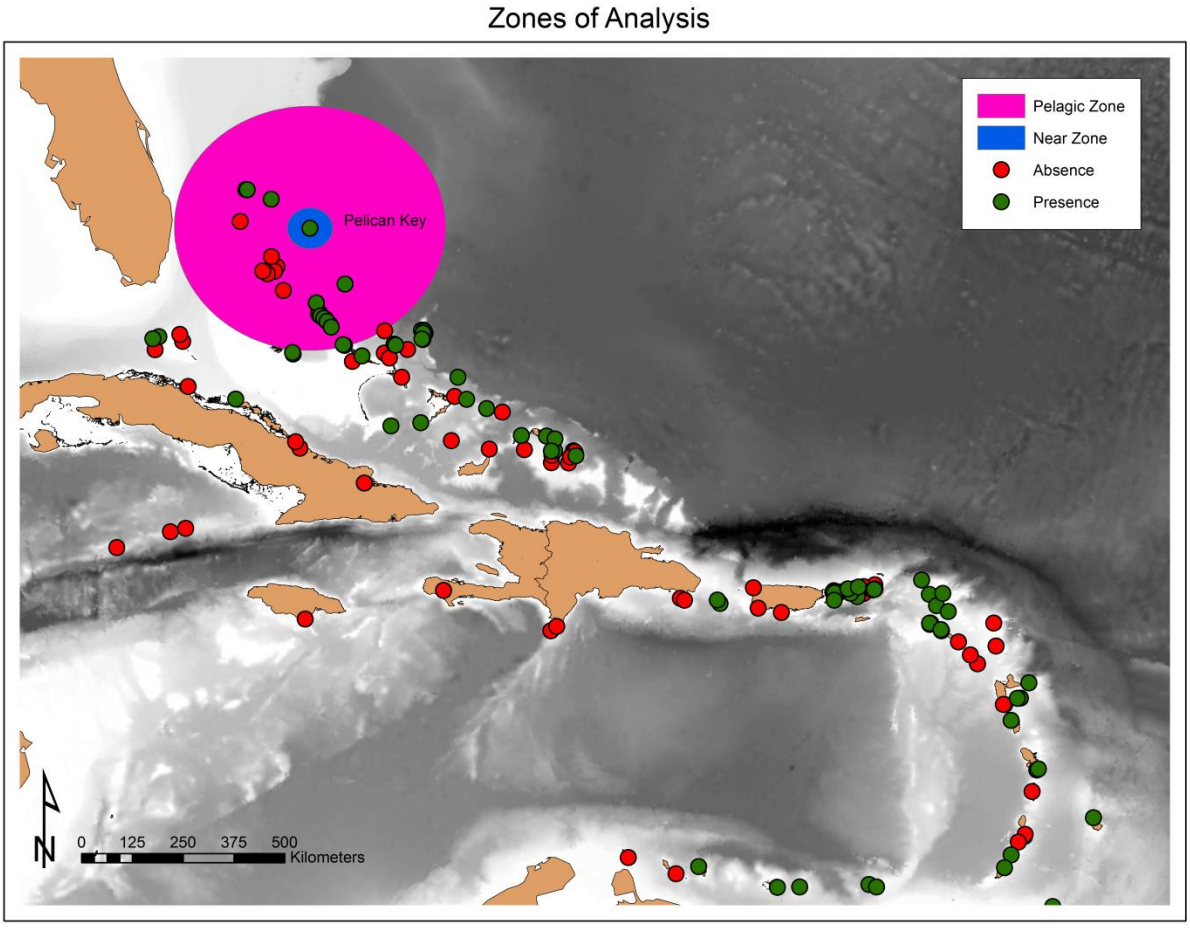

Figure 2. Zones of Analysis. This figure gives an example of what the two zones of analysis look like, using Pelican Key as the site from which the analysis is based around.

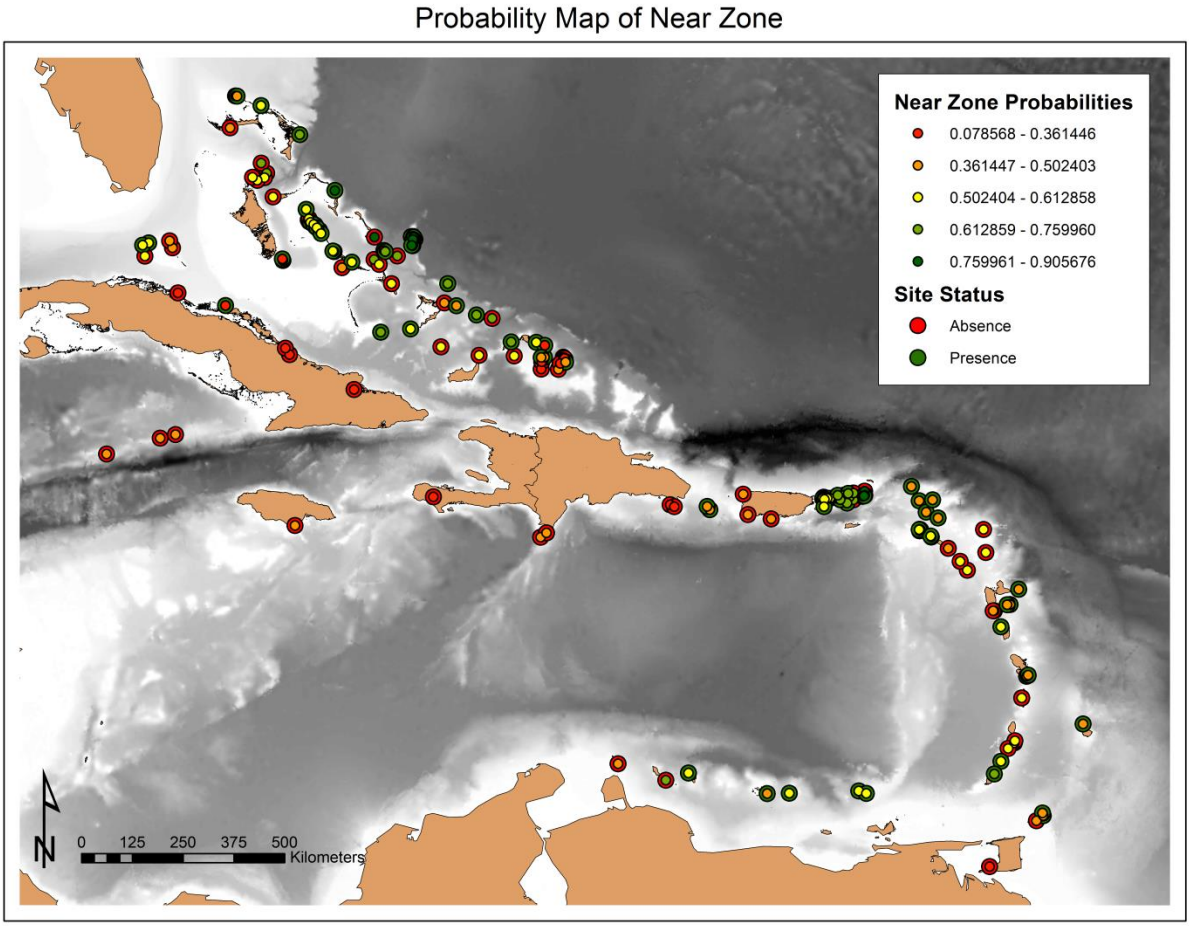

Figure 3. Probability Map of Near Zone. A map representation of the Near Zone logistic regression model showing both actual presence and absences site status and the probabilities predicted by the logistic regression equation.

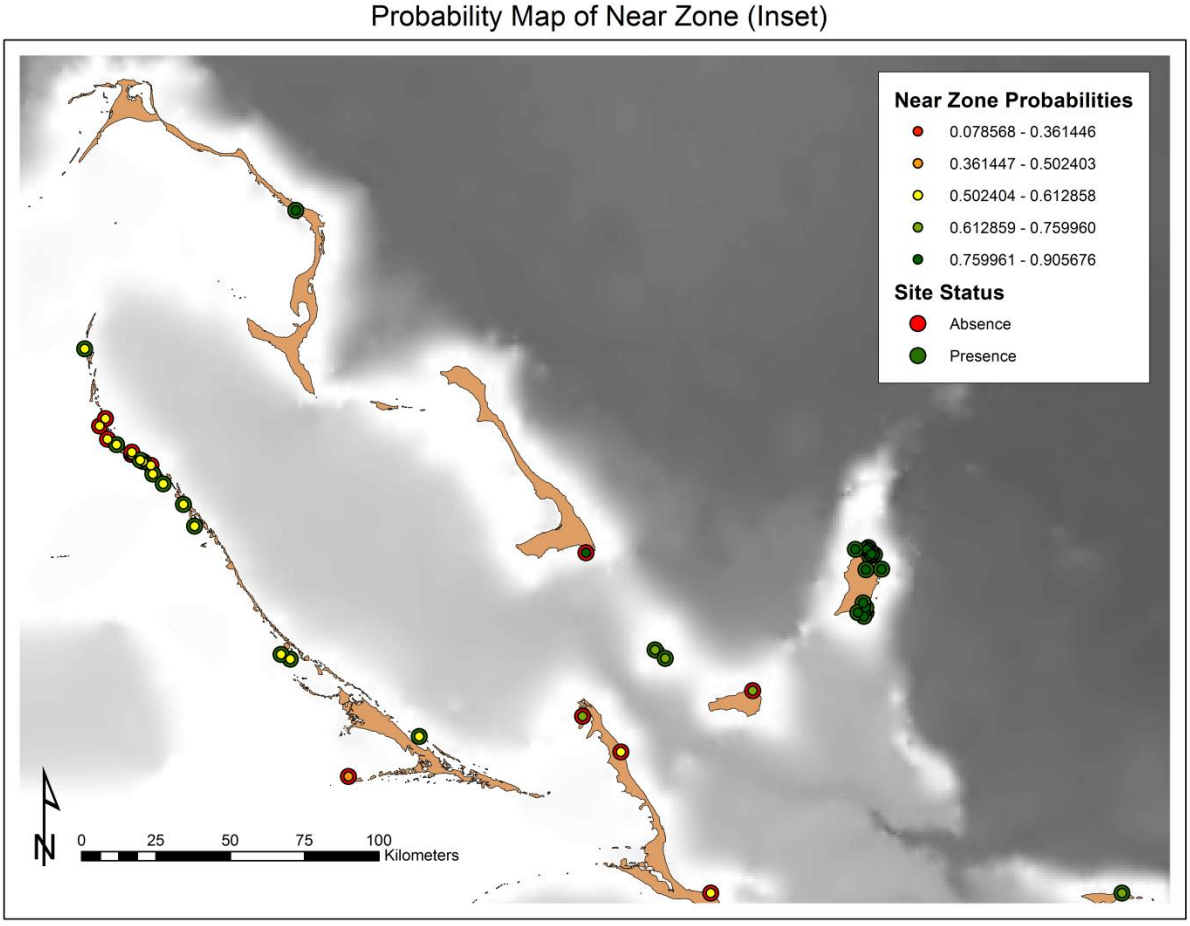

Figure 4. Probability Map of Near Zone (Inset). Subset of Figure 3 depicting the results of the analysis around the Exuma Island Chain and San Salvador Island, Bahamas.

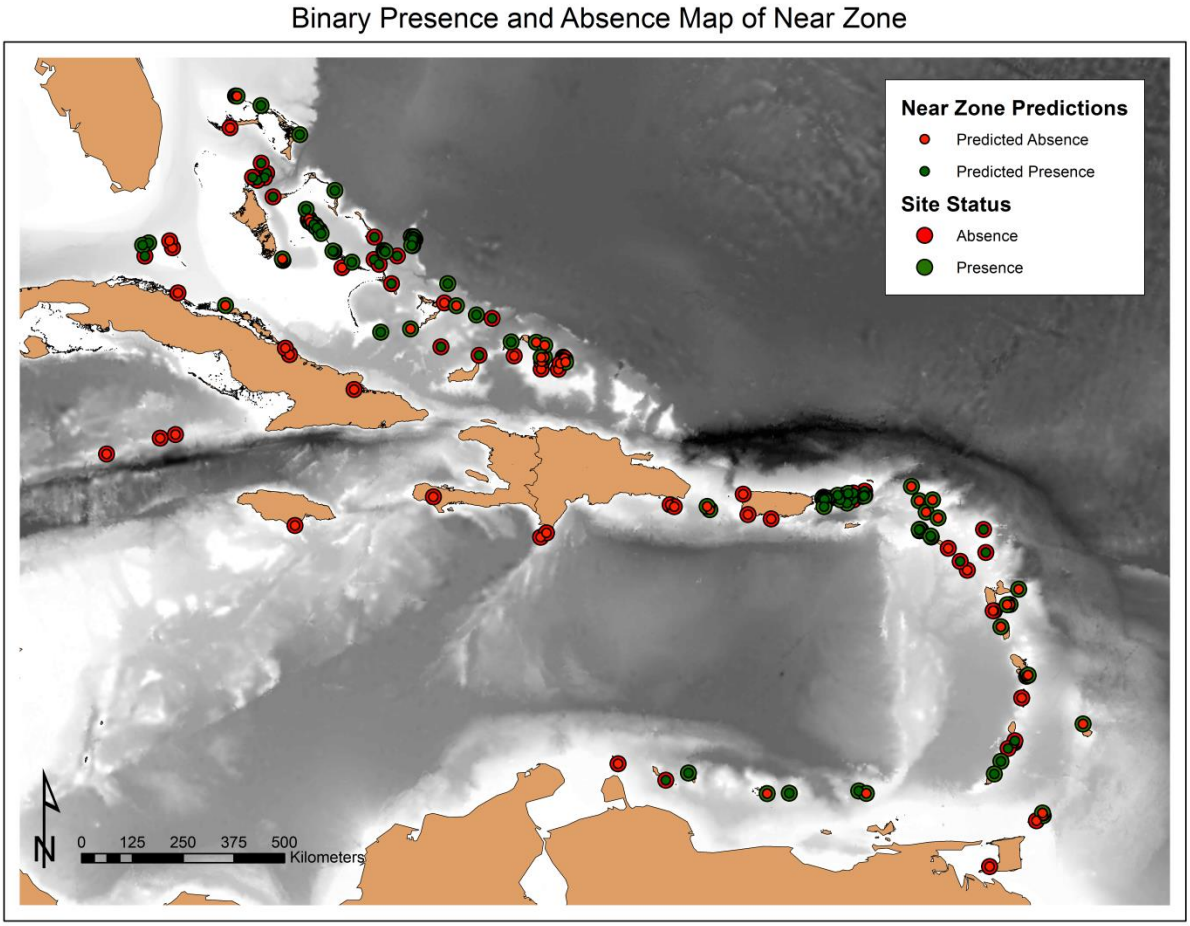

Figure 5. Binary Presence and Absence Map for Near Zone. This figure compares the actual presence and absence sites to the predicted presence and absences from the Near Zone logistic regression model.

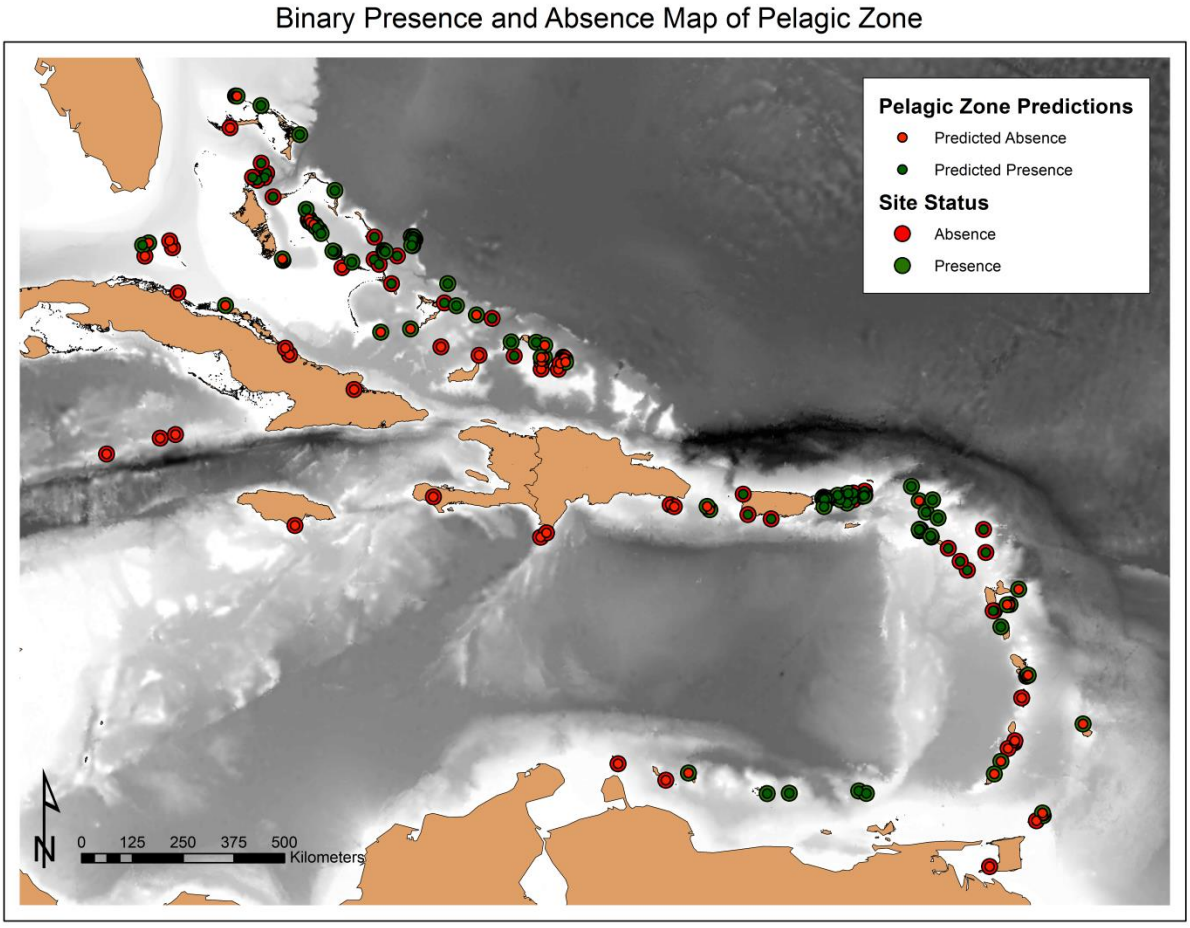

Figure 6. Binary Presence and Absence Map for Pelagic Zone. This map compares actual presence and absence sites to those predicted by the Pelagic Zone logistic regression model.

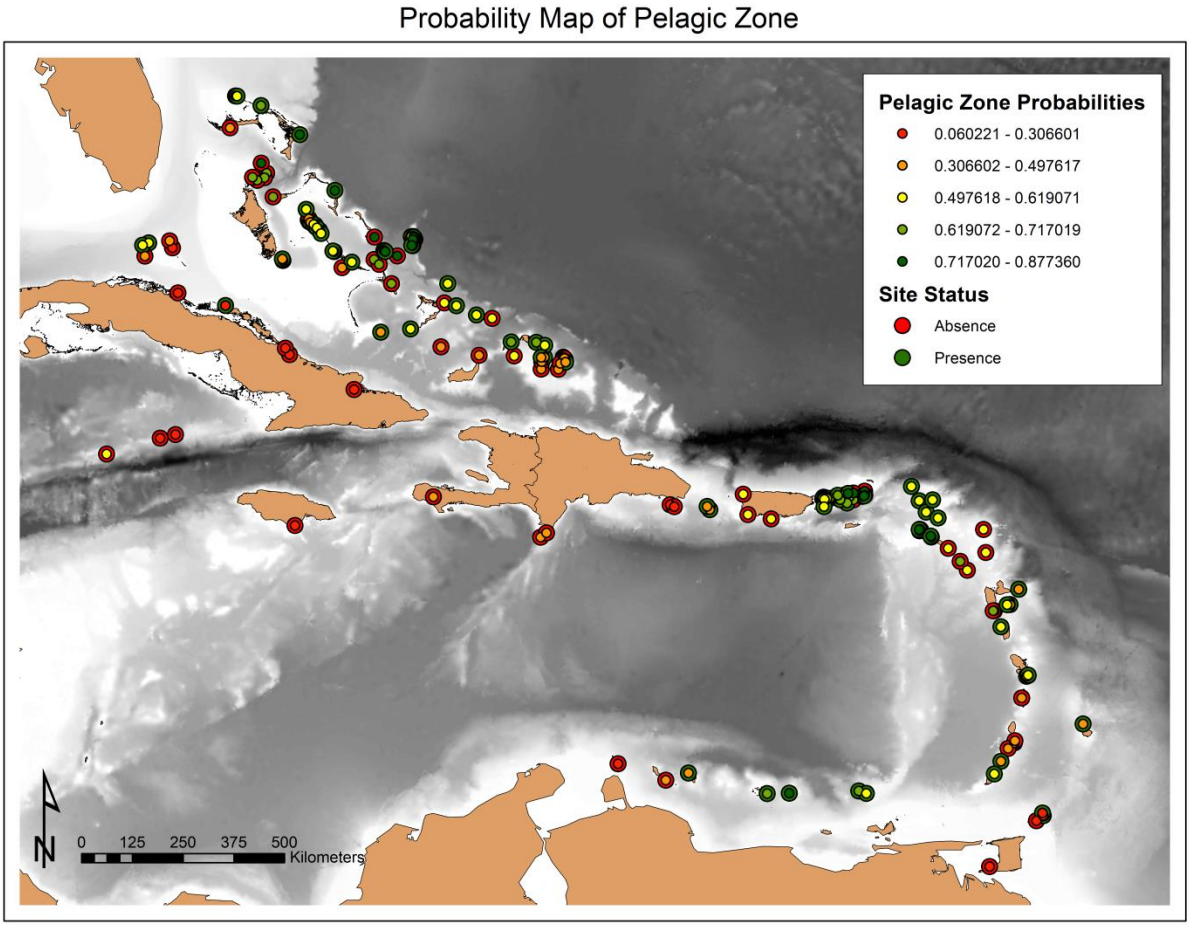

Figure 7. Probability Map of Pelagic Zone. This map shows the actual presence and absence sites compared to the probability values predicted by the Pelagic Zone logistic regression equation.

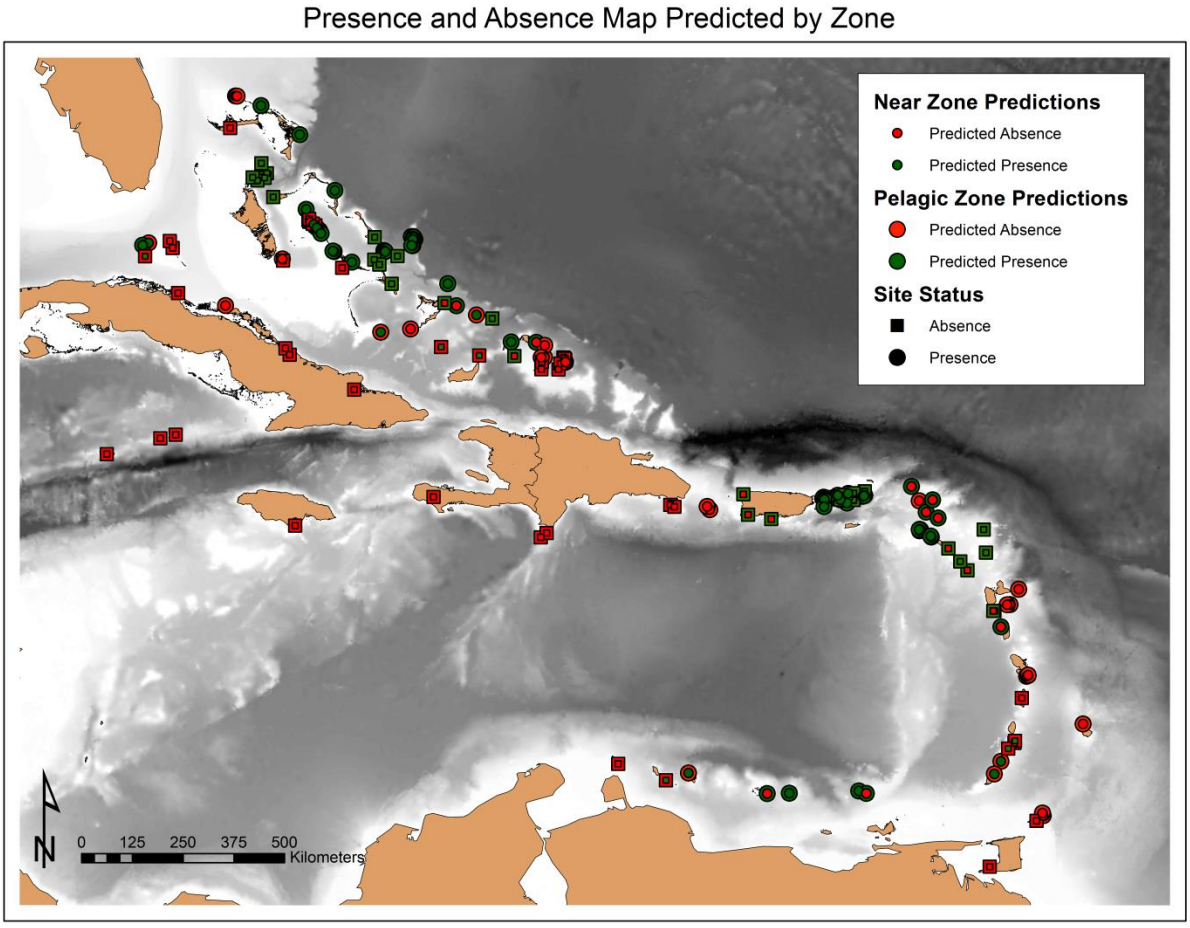

Figure 8. Presence and Absence Map Predicted by Zone. This map compares the predicted presence and absence sites for both the Near and Pelagic Zone. Two distinct geographic patterns emerge: either zone can be used in the Northern Caribbean to achieve similar results, but the results of the two zones in the Lesser Antilles are not consistent.

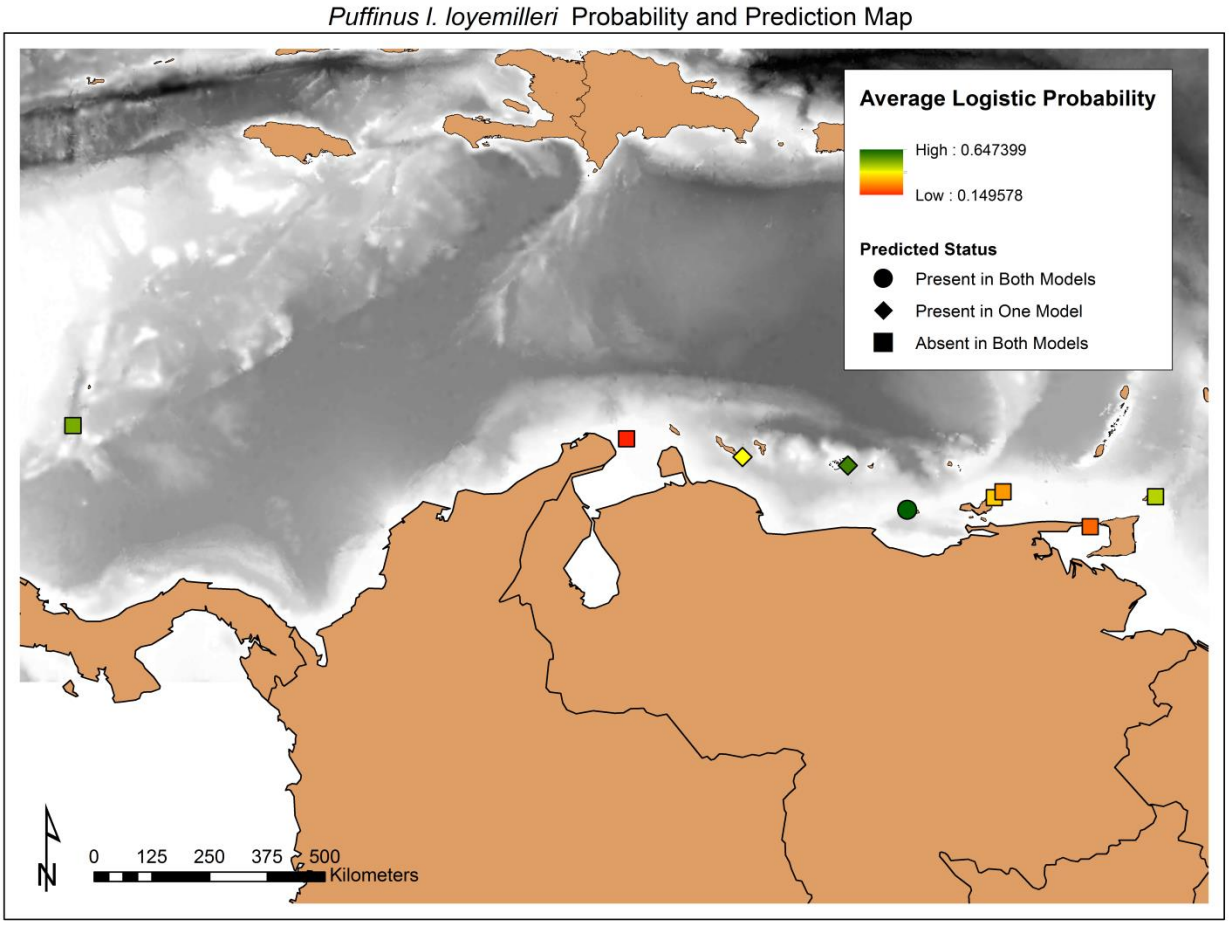

Figure 9. *Puffinus l. loyemilleri* Probability and Prediction Map. This map shows the results of the *P. l. loyemilleri* analysis. The map displays the results both by the results of the predicted site status and the average probability of the two logistic equations.

Appendix C: Main Shearwater Shapefile Format

Presence and Absence	Island Name	Island Group	Major Chain	Survey Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	DEM Available	Longitude	Latitude	Near Zone Probability	Near Prediction	Pelagic-Zone Probability	Pelagic Prediction	Data Source
0	Absence 1 Alligator Cay	Exumas	Great Bahama Bank	1994	0	0	1	1	0	1	0	0	0	0	0	0	yes	-76.63875586	24.39292234	0.55412524	1	0.52152382	0	Bradley and Norton 2009
0	Absence 2 Boat House Rock	Rum Cay	Eastern Bahamas	1989	0	0	0	0	0	0	0	0	0	0	0	0	yes	-74.8390161	23.68546801	0.67048523	1	0.73998074	1	Bradley and Norton 2009
0	Absence 3 Booby Cay	Mayaguana	Southern Bahamas	1998	0	0	1	1	1	0	0	0	0	0	0	0	yes	-72.71784466	22.32604343	0.69824584	1	0.56054599	1	Bradley and Norton 2009
0	Absence 4 Cay Sal	Cay Sal	Cay Sal Bank	1996	0	0	0	1	1	0	0	0	0	0	0	0	yes	-80.41148974	23.70855721	0.55804135	1	0.43547663	0	Bradley and Norton 2009
0	Absence 5 Damas Cay	Cay Sal	Cay Sal Bank	1996	0	0	0	1	1	0	0	0	0	0	0	0	yes	-79.80097517	23.89295484	0.46513069	0	0.30177762	0	Bradley and Norton 2009
0	Absence 6 Danger Cay	Exumas	Great Bahama Bank	2006	0	0	0	1	1	1	0	0	0	0	0	0	yes	-76.69735187	24.4263244	0.53285762	1	0.4976166	0	Bradley and Norton 2009
0	Absence 7 Dog Rocks	Cay Sal	Cay Sal Bank	1996	0	0	0	1	1	1	0	0	0	0	0	0	yes	-79.8625996	24.04836612	0.47431598	0	0.32167207	0	Bradley and Norton 2009
0	Absence 8 Dolly's Rock	South Andros	Great Bahama Bank	1984	0	0	0	1	1	1	0	0	0	0	0	0	yes	-77.67985202	23.7454588	0.32300055	0	0.38790715	0	Bradley and Norton 2009
0	Absence 9 Duck Cay	Exumas	Great Bahama Bank	1999	0	0	0	1	1	1	0	0	0	0	0	0	yes	-76.04143066	23.45117567	0.49833886	0	0.49073844	0	Bradley and Norton 2009
0	Absence 10 Frozen Cay	Berry Islands	Great Bahama Bank	2002	0	0	0	1	1	1	0	0	0	0	0	0	yes	-77.71807596	25.57197674	0.62124014	1	0.69296406	1	Bradley and Norton 2009
0	Absence 11 Gallion Cay	Long Island	Great Bahama Bank	1991	0	0	0	1	1	1	0	0	0	0	0	0	yes	-75.33333335	23.63333335	0.62535502	1	0.69430092	1	Bradley and Norton 2009
0	Absence 12 Gold Rock	Acklins	Southern Bahamas	1997	0	0	0	1	1	1	0	0	0	0	0	0	yes	-73.38657794	22.67092095	0.39513699	0	0.6068597	1	Bradley and Norton 2009
0	Absence 13 Goulding Cay	New Providence	Great Bahama Bank	2003	0	0	0	1	1	1	0	0	0	0	0	0	yes	-77.57024759	25.00071406	0.56996433	1	0.64841986	1	Bradley and Norton 2009
0	Absence 14 Guana Cay	Cat Island	Great Bahama Bank	1986	0	0	0	1	1	1	0	0	0	0	0	0	yes	-75.32497744	24.1493838	0.79020312	1	0.7604901	1	Bradley and Norton 2009
0	Absence 15 Hawksbill Cay	Exumas	Great Bahama Bank	2000	0	0	0	1	1	1	0	0	0	0	0	0	yes	-76.7712008	24.49615511	0.51534748	0	0.47191345	0	Bradley and Norton 2009
0	Absence 16 Hogsty Reef	Great Inagua	Southern Bahamas	1979	0	0	0	1	1	1	0	0	0	0	0	0	yes	-73.32380465	21.0657043	0.55838062	1	0.4579449	0	Bradley and Norton 2009
0	Absence 17 Little Inagua	Little Inagua	Southern Bahamas	1999	0	0	0	1	1	1	0	0	0	0	0	0	yes	-73.00540098	21.50611239	0.56890205	1	0.48754149	0	Bradley and Norton 2009
0	Absence 18 Little Pigeon	Exumas	Great Bahama Bank	1998	0	0	0	1	1	1	0	0	0	0	0	0	yes	-76.79400816	24.51262545	0.52555028	0	0.4629373	0	Bradley and Norton 2009
0	Absence 19 Little Whale Cay	Berry Islands	Great Bahama Bank	2002	0	0	0	1	1	1	0	0	0	0	0	0	yes	-77.75996685	25.44857939	0.57497611	1	0.68144724	1	Bradley and Norton 2009
0	Absence 20 Mamma Rhoda Rock	Berry Islands	Great Bahama Bank	2002	0	0	0	1	1	1	0	0	0	0	0	0	yes	-77.92116463	25.40762923	0.57424489	1	0.66803828	1	Bradley and Norton 2009
0	Absence 21 Meritek Pond	Long Island	Great Bahama Bank	1990	0	0	0	0	0	0	0	0	0	0	0	0	yes	-75.0961555	23.176424	0.58976285	1	0.71315875	1	Bradley and Norton 2009
0	Absence 22 Peterson Cay	Grand Bahama	Little Bahama Bank	2004	0	0	0	1	1	1	0	0	0	0	0	0	no	-78.52308592	26.55191792	0.45825203	0	0.4545294	0	Bradley and Norton 2009
0	Absence 23 Petits Cay	Berry Islands	Great Bahama Bank	2002	0	0	0	1	1	1	0	0	0	0	0	0	yes	-77.83412527	25.77161636	0.63100413	1	0.72565215	1	Bradley and Norton 2009
0	Absence 24 Rum Cay	Berry Islands	Great Bahama Bank	2002	0	0	0	1	1	1	0	0	0	0	0	0	yes	-77.84506562	25.73285125	0.59440487	1	0.70967532	1	Bradley and Norton 2009
0	Absence 25 Saddle Cay	Exumas	Great Bahama Bank	2006	0	0	0	1	1	1	0	0	0	0	0	0	yes	-76.8085997	24.63590076	0.50714548	0	0.45394342	0	Bradley and Norton 2009
0	Absence 26 Shroud Cay	Exumas	Great Bahama Bank	2005	0	0	0	1	1	1	0	0	0	0	0	0	yes	-76.77639436	24.75045427	0.52691268	0	0.46545671	0	Bradley and Norton 2009
0	Absence 27 Strachan Cay	Long Island	Great Bahama Bank	1990	0	0	0	1	1	1	0	0	0	0	0	0	yes	-74.94547975	23.0981619	0.5428687	1	0.67449157	1	Bradley and Norton 2009
0	Absence 28 Big Sand Cay	Turks	Turks Bank	2002	0	0	0	1	1	1	0	0	0	0	0	0	yes	-71.24841124	21.19727894	0.46290664	0	0.3509286	0	Bradley and Norton 2009
0	Absence 29 Bush Cays	Bush and Seals	Caicos Bank	2002	0	0	0	1	1	1	0	0	0	0	0	0	yes	-71.62843571	21.20120254	0.35579312	0	0.41299592	0	Bradley and Norton 2009
0	Absence 30 Fish Cay	Outer Caicos	Caicos Bank	2002	0	0	0	1	1	1	0	0	0	0	0	0	yes	-71.61756106	21.36079657	0.33789568	0	0.40122889	0	Bradley and Norton 2009
0	Absence 31 French Island	Caicos	Caicos Bank	2002	0	0	0	1	1	1	0	0	0	0	0	0	yes	-72.2267707	21.49303768	0.52727039	0	0.56287134	1	Bradley and Norton 2009
0	Absence 32 Grand Turk	Turks	Turks Bank	2004	0	0	0	1	1	1	0	0	0	0	0	0	yes	-71.13892904	21.46745869	0.30061926	0	0.37888168	0	Bradley and Norton 2009
0	Absence 33 Long Cay	Turks	Turks Bank	2002	0	0	0	1	1	1	0	0	0	0	0	0	yes	-71.10963833	21.41352109	0.28861621	0	0.3591059	0	Bradley and Norton 2009
0	Absence 34 Pennisten Cay	Turks	Turks Bank	2002	0	0	0	1	1	1	0	0	0	0	0	0	yes	-71.12244125	21.37615813	0.45902622	0	0.35717043	0	Bradley and Norton 2009
0	Absence 35 Round Cay	Turks	Turks Bank	2002	0	0	0	1	1	1	0	0	0	0	0	0	yes	-71.11254422	21.44112041	0.29384718	0	0.3679023	0	Bradley and Norton 2009
0	Absence 36 Salt Cay	Turks	Turks Bank	2004	0	0	0	1	1	1	0	0	0	0	0	0	yes	-71.20722811	21.32929861	0.28860779	0	0.34919689	0	Bradley and Norton 2009
0	Absence 37 Ballenato Cayo	Camaguey	Cuba	2004	0	0	0	1	1	1	0	0	0	0	0	0	yes	-77.20444677	21.52395102	0.31677915	0	0.13487	0	Bradley and Norton 2009
0	Absence 38 Cayos Broqueles	Nipe Bay	Cuba	1998	0	0	0	1	1	1	0	0	0	0	0	0	no	-75.77396758	20.75162885	0.31028161	0	0.12982973	0	Bradley and Norton 2009
0	Absence 39 Dutton Cayo	Los Palanales	Cuba	2004	0	0	0	1	1	1	0	0	0	0	0	0	yes	-79.67775267	22.89134927	0.24207924	0	0.08331495	0	Bradley and Norton 2009
0	Absence 40 Sabinal Cayo	Cuba	Cuba	2004	0	0	0	2	2	2	0	0	0	0	0	0	yes	-77.30000151	21.66666745	0.32675373	0	0.14693299	0	Bradley and Norton 2009
0	Absence 41 Booby Pond	Little Cayman	Cayman Islands	2001	0	0	0	2	2	2	0	0	0	0	0	0	yes	-80.07289381	19.67259498	0.47585526	0	0.22586256	0	Bradley and Norton 2009
0	Absence 42 E Cayman Brac Bluff	Cayman Brac	Cayman Islands	2003	0	0	0	2	2	2	0	0	0	0	0	0	yes	-79.73218029	19.74827888	0.42708883	0	0.13959126	0	Bradley and Norton 2009
0	Absence 43 North Sound Estates	Grand Cayman	Cayman Islands	1995	0	0	0	2	2	2	0	0	0	0	0	0	yes	-81.26233787	19.32010386	0.44483933	0	0.51434523	0	Bradley and Norton 2009
0	Absence 44 Little Half Moon	Portland Bight	Jamaica	2005	1	0	0	2	2	2	0	0	0	0	0	0	no	-77.08690573	17.73470858	0.42245393	0	0.29373874	0	Bradley and Norton 2009
0	Absence 45 Isla Alto Velo	Dominican Republic	Hispaniola	2005	0	0	2	2	2	0	0	0	0	0	0	0	yes	-71.64083384	17.47305559	0.42298073	0	0.36548486	0	Bradley and Norton 2009
0	Absence 46 Beata Island	Dominican Republic	Hispaniola	2005	0	0	2	2	2	0	0	0	0	0	0	0	yes	-71.5133044	17.5704899	0.44459506	0	0.41216178	0	Bradley and Norton 2009
0	Absence 47 Paso de Catuan	Saona	Hispaniola	2005	0	0	2	2	2	0	0	0	0	0	0	0	yes	-68.73626141	18.30505535	0.27208104	0	0.2912805	0	Bradley and Norton 2009
0	Absence 48 Pic Macaya	Massif de la Hotte	Hispaniola	1999	0	0	0	2	2	2	0	0	0	0	0	0	yes	-74.01868469	18.37061082	0.36144613	0	0.34699855	0	Bradley and Norton 2009
0	Absence 49 Saona	Dominican Republic	Hispaniola	1998	0	0	0	2	2	2	0	0	0	0	0	0	yes	-68.67973619	18.1530884	0.28356071	0	0.30660134	0	Bradley and Norton 2009
0	Absence 50 La Parguera	Lajas	Puerto Rico	2005	0	1	1	1	1	1	0	0	0	0	0	0	yes	-67.04661031	17.97486575	0.45973774	0	0.57156842	1	Bradley and Norton 2009
0	Absence 51 Morrillito	Ponce	Puerto Rico	2005	0	1	1	1	1	1	0	0	0	0	0	0	no	-66.53409478	17.87989748	0.43113993	0	0.60176679	1	Bradley and Norton 2009
0	Absence 52 Aguadilla	Aguadilla	Puerto Rico	2005	0	1	1	1	1	1	1	0	0	0	0	0	yes	-67.15406981	18.4274439	0.42937349	0	0.56200507	1	Bradley and Norton 2009
0	Absence 53 Booby Rock	St. John	U.S. Virgin	1990	1	1	1	1	1	1	0	0	0	0	0	0	no	-64.70990187	18.3023201	0.7128262	1	0.7146489	1	Bradley and Norton 2009
0	Absence 54 Carval Rock	U.S. Virgin	Leeward Islands	1999	1	1	1	1	1	1	0	0	0	0	0	0	yes	-64.79813977	18.3684685	0.69164735	1	0.68726855	1	Bradley and Norton 2009
0	Absence 55 Dutchcap Cay	St. Thomas	Leeward Islands	1999	1	1	1	1	1	1	0	0	0	0	0	0	yes	-65.06182085	18.37953252	0.64694933	1	0.70461859	1	Bradley and Norton 2009
0	Absence 56 Kalkun Cay	St. Thomas	Leeward Islands	1999	1	1	1	1	1	1	0	0	0	0	0	0	no	-65.05738739	18.3495982	0.65240218	1	0.70383308	1	Bradley and Norton 2009
0	Absence 57 Little Hans Lollick Island	St. Thomas	Leeward Islands	1999	1	1	1	1	1	1	0	0	0	0	0	0	yes	-64.90743854	18.41023678	0.67838627	1	0.67800733	1	Bradley and Norton 2009
0	Absence 58 Turtledove Cay	U.S. Virgin	Leeward Islands	1997	1	1	1	1	1	1	0	0	0	0	0	0	yes	-65.00029538	18.30864686	0.67815895	1	0.70284607	1	Bradley and Norton 2009
0	Absence 59 Cockroach	Virgin Gorda	Leeward Islands	2005	1	1	0	0	0	0	0	0	0	0	0	1	no	-64.46255949	18.4960056	0.81794298	1	0.77555009	1	Bradley and Norton 2009
0	Absence 60 Green Cay	Jost van Dyke	Leeward Islands	2005	1	1	0	0	0	0	0	0	0	0	0	1	yes	-64.70986366	18.4541725	0.73186511	1	0.75429835	1	Bradley and Norton 2009
0	Absence 61 Grand Islet	The Saints	Leeward Islands	1998	0	0	2	2	2	0	0	0	0	0	0	0	yes	-61.58609394	15.84032405	0.4776203	0	0.65146318	1	Bradley and Norton 2009
0	Absence 62 Les Augustins	Les Augustins	Leeward Islands	1998	0	0	2	2	2	0	0	0	0	0	0	0	no	-61.61167423	15.84418974	0.48181827	0	0.65347576	1	Bradley and Norton 2009
0	Absence 63 Booby Island	St. Kitts	Leeward Islands	2004	0	0	2	2	2	0	0	0	0	0	0	0	no	-62.61020264	17.22682584	0.48540171	0	0.61297533	1	Bradley and Norton 2009
0	Absence 64 Monserrat	Montserrat	Leeward Islands	2005	0	0	2	2	2	0	0	0	0	0	0	0	yes	-62.18740598	16.74254385	0.50461879	0	0.61907113	1	Bradley and Norton 2009
0	Absence 65 Burma Quarry	Antigua	Leeward Islands	1999	0	0	2	2	2	0	0	0	0	0	0	0	yes	-61.77536107	17.13640973	0.5824668	1	0.60038953	1	Bradley and Norton 2009
0	Absence 66 Codrington Lagoon	Barbuda	Leeward Islands	1999	0	0	2	2	2	0	0	0	0	0	0	0	yes	-61.82576863	17.64459569	0.53927561	1	0.61892137	1	Bradley and Norton 2009
0	Absence 67 Redondo Island	Redondo	Leeward Islands	2004	0	0	2	2	2	0	0	0	0	0	0	0	yes	-62.34551394	16.9384745	0.53172375	1	0.63756565	1	Bradley and Norton 2009
0	Absence 68 St. Lucia Island	St. Lucia	Leeward Islands	2005	0	0	2	2	2	0	0	0	0	0	0	0	yes	-60.97900901	13.90970286	0.58002399	0	0.49371218	0	Bradley and Norton 2009
0	Absence 69 All-Awash Island	Grenadines	Windward Islands	2004	0	0	2	2	2	0	0	0	0	0	0	0	yes	-61.14324599	12.91526165	0.51470247	0	0.47404892	0	Bradley and Norton 2009
0	Absence 70 Bartowia	Grenadines	Windward Islands	2005	0	0	2	2	2	0	0	0	0	0	0	0	yes	-61.13192782	12.96153933	0.53477401	1	0.48839955	0	Bradley and Norton 2009
0	Absence 71 Petit Canouan	Grenadines	Windward Islands	2004	0	0	2	2	2	0	0	0	0	0	0	0	yes	-61.28266527	12.70891585	0.55659386	1	0.44842661	0	Bradley and Norton 2009
0	Absence 72 Smith's Island	Trinidad	South America	1998	2	2	2	2	0	0	0	0	0	0	0	0	no	-60.65264425	11.18441746	0.46541087	0	0.22678868	0	Bradley and Norton 2009
0	Absence 73 Southwest Coast	Trinidad	South America	1984	2	2	2	2	0	0	0	0	0	0	0	0	yes	-61.69044715	10.16993736	0.09518923	0	0.06962157	0	Bradley and Norton 2009
0	Absence 74 Lago Reef	Aruba	South America	2002	2	2	0	0	0	0	0	0	0	0	0	0	yes	-69.92822614	12.44731758	0.43245771	0	0.11170561	0	Bradley and Norton 2009
0	Absence 75 Lagoon of Janthiel	Curacao	Curacao	2002	2	2	0	0	0	0	0	0	0	0	0	0	yes	-68.86903236	12.08546828	0.6366967	1	0.43087156	0	Bradley and Norton 2009
1	Allan's Cay	Exumas	Great Bahama Bank	2003	0	0	1	1	1	1	0	0	0	0	0	0	yes	-76.84128888	24.74085247	0.53781235	1	0.56437738	1	Bradley and Norton 2009
1	Atwood Cay	Samana Cay	Southern Bahamas	1999	0	0	1	1	1	1	0	0	0	0	0	0	no	-73.70143443	23.08578702	0.75996013	1	0.6103629	1	Bradley and Norton 2009
1	Cato Cay	San Salvador	Eastern Bahamas	2003	0	0	0	1	1	1	0	0	0	0	0	0	no	-74.46857669	24.14388224	0.90148997	1	0.76936785	1	Bradley and Norton 2009
1	Cay Verde	Ragged Islands	Great Bahama Bank	1998	0	0	0	1	1	1	0	0	0	0	0	0	yes	-75.18485676	22.02068209	0.64958029	1	0.49328057	0	Bradley and Norton 2009
1	Channel Cay	Exumas	Great Bahama Bank	2002	0	0	1	1	1	1	0	0	0	0	0	0	yes	-75.80129354	23.55691323	0.54554536	1	0.57830487	1	Bradley and Norton 2009

Presence and Absence	Island Name	Island Group	Major Chain	Survey Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	DEM Available	Longitude	Latitude	Near Zone Probability	Near Prediction	Pelagic Zone Probability	Pelagic Prediction	Data Source
1	Conception Island	Conception	Eastern Bahamas	1998	0	0	1	1	1	0	0	0	0	0	0	0	yes	-75.11367212	23.83453895	0.6789784	1	0.74877395	1	Bradley and Norton 2009
1	Cut Cay	San Salvador	Eastern Bahamas	2003	0	0	1	1	1	0	0	0	0	0	0	0	yes	-74.45920936	24.12846231	0.90472858	1	0.77329286	1	Bradley and Norton 2009
1	Double-headed Shots Cay	Cay Sal	Cay Sal Bank	1984	0	0	1	1	1	0	0	0	0	0	0	0	yes	-80.32927579	23.99931858	0.56451197	1	0.53811449	0	Bradley and Norton 2009
1	East Pimblico Cay	Exumas	Great Bahama Bank	2002	0	0	1	1	1	0	0	0	0	0	0	0	yes	-76.21702985	23.80683946	0.55477241	1	0.59742688	1	Bradley and Norton 2009
1	East Plana Cay	Plana Cays	Southern Bahamas	1998	0	0	1	1	1	0	0	0	0	0	0	0	yes	-73.50850128	22.6065019	0.45860411	0	0.5756864	1	Bradley and Norton 2009
1	Elbow Cay	Cay Sal	Cay Sal Bank	2005	0	0	1	1	1	0	0	0	0	0	0	0	yes	-80.4612004	23.95086894	0.58880033	1	0.57366748	1	Bradley and Norton 2009
1	Eleuthera Island	Eleuthera	Great Bahama Bank	1999	0	0	1	1	1	0	0	0	0	0	0	0	yes	-76.66449392	25.46775652	0.78672554	1	0.73565113	1	Bradley and Norton 2009
1	Fish Cay	Abaco	Little Bahama Bank	1998	0	0	1	1	1	0	0	0	0	0	0	0	yes	-77.83689259	27.04863241	0.57031996	1	0.69661529	1	Bradley and Norton 2009
1	Gaulin Cay	San Salvador	Eastern Bahamas	2003	0	0	1	1	1	0	0	0	0	0	0	0	no	-74.47322061	24.13824961	0.90205034	1	0.76992598	1	Bradley and Norton 2009
1	Goulding Cay	San Salvador	Eastern Bahamas	2003	0	0	1	1	1	0	0	0	0	0	0	0	no	-74.42851587	24.07882825	0.89984021	1	0.76890724	1	Bradley and Norton 2009
1	Graham's Harbour	San Salvador	Eastern Bahamas	2003	0	0	1	1	1	0	0	0	0	0	0	0	yes	-74.46467022	24.11842599	0.90567597	1	0.77432443	1	Bradley and Norton 2009
1	Green Cay	San Salvador	Eastern Bahamas	2003	0	0	1	1	1	0	0	0	0	0	0	0	yes	-74.50762714	24.13889479	0.80220407	1	0.59559261	1	Bradley and Norton 2009
1	High Cay	San Salvador	Eastern Bahamas	2003	0	0	1	1	1	0	0	0	0	0	0	0	yes	-74.4761704	23.94773272	0.89923737	1	0.75257844	1	Bradley and Norton 2009
1	Little Cistern Cay	Exumas	Great Bahama Bank	2006	0	0	1	1	1	0	0	0	0	0	0	0	yes	-76.74259965	24.45623794	0.5237559	0	0.47778927	0	Bradley and Norton 2009
1	Little Walker's Cay	Walker's Cay	Little Bahama Bank	1999	0	0	1	1	1	0	0	0	0	0	0	0	yes	-78.40311138	27.25921063	0.47620248	0	0.51573001	0	Bradley and Norton 2009
1	Long Cay	Exumas	Great Bahama Bank	2000	0	0	1	1	1	0	0	0	0	0	0	0	yes	-76.11532404	23.69446806	0.55051756	1	0.51498662	0	Bradley and Norton 2009
1	Low Cay	San Salvador	Eastern Bahamas	2003	0	0	1	1	1	0	0	0	0	0	0	0	yes	-74.48221653	23.93640317	0.89859675	1	0.75202626	1	Bradley and Norton 2009
1	Malabars Cay	Exumas	Great Bahama Bank	2006	0	0	1	1	1	0	0	0	0	0	0	0	yes	-76.63277599	24.36674638	0.55831458	1	0.52507641	0	Bradley and Norton 2009
1	Man Head Cay	San Salvador	Eastern Bahamas	2003	0	0	1	1	1	0	0	0	0	0	0	0	no	-74.45036063	24.12300032	0.90566199	1	0.77192477	1	Bradley and Norton 2009
1	Mayaguana Island	Mayaguana	Southern Bahamas	2005	0	0	1	1	1	0	0	0	0	0	0	0	yes	-73.06414672	22.40177941	0.70583693	1	0.55904969	0	Bradley and Norton 2009
1	Nancy Cay	San Salvador	Eastern Bahamas	2000	0	0	1	1	1	0	0	0	0	0	0	0	yes	-74.47622235	23.96266579	0.89659034	1	0.75334502	1	Bradley and Norton 2009
1	Noddy Cay	Exumas	Great Bahama Bank	2000	0	0	1	1	1	0	0	0	0	0	0	0	no	-76.13261635	23.69548413	0.54815981	1	0.51852314	0	Bradley and Norton 2009
1	North Point Bluff Cay	San Salvador	Eastern Bahamas	2000	0	0	1	1	1	0	0	0	0	0	0	0	yes	-74.45885608	24.1245631	0.90539653	1	0.77413014	1	Bradley and Norton 2009
1	Pelican Cay	Abaco	Little Bahama Bank	2004	0	0	1	1	1	0	0	0	0	0	0	0	yes	-76.97975793	26.40303427	0.75574909	1	0.87736031	1	Bradley and Norton 2009
1	Pigeon Creek	San Salvador	Eastern Bahamas	2003	0	0	1	1	1	0	0	0	0	0	0	0	yes	-74.48428124	23.97658496	0.89504384	1	0.757077	1	Bradley and Norton 2009
1	Rocky Dundas	Exumas	Great Bahama Bank	1994	0	0	1	1	1	0	0	0	0	0	0	0	yes	-76.54056214	24.27497196	0.58855289	1	0.57270872	1	Bradley and Norton 2009
1	San Salvador Island	San Salvador	Eastern Bahamas	1999	0	0	1	1	1	0	0	0	0	0	0	0	yes	-74.47601941	24.07755647	0.90078893	1	0.76965049	1	Bradley and Norton 2009
1	Sandy Cay	Exumas	Great Bahama Bank	2005	0	0	1	1	1	0	0	0	0	0	0	0	yes	-75.43395281	23.40381154	0.60653901	1	0.60402565	1	Bradley and Norton 2009
1	South Mira-Por Vos Island	Mira-por-vos	Southern Bahamas	1987	0	0	1	1	1	0	0	0	0	0	0	0	yes	-74.52518163	22.09168721	0.51570965	0	0.53780197	0	Bradley and Norton 2009
1	South Rocks Cay	Conception	Eastern Bahamas	1998	0	0	1	1	1	0	0	0	0	0	0	0	yes	-75.08327253	23.80901527	0.65557644	1	0.7472238	1	Bradley and Norton 2009
1	The Gulf Bluffs	San Salvador	Eastern Bahamas	2000	0	0	1	1	1	0	0	0	0	0	0	0	yes	-74.5005319	23.94795359	0.89290652	1	0.74797377	1	Bradley and Norton 2009
1	Tom Brown's Cay	Walker's Cay	Little Bahama Bank	1984	0	0	1	1	1	0	0	0	0	0	0	0	yes	-78.4111292	27.26621205	0.47430737	0	0.51271053	0	Bradley and Norton 2009
1	Twins Cay	Exumas	Great Bahama Bank	1994	0	0	1	1	1	0	0	0	0	0	0	0	yes	-76.50675824	24.2095473	0.59335081	1	0.59187236	1	Bradley and Norton 2009
1	Washerwoman Cay	South Andros	Great Bahama Bank	1984	0	0	1	1	1	0	0	0	0	0	0	0	yes	-77.36522982	23.64693755	0.34099923	0	0.42025391	0	Bradley and Norton 2009
1	West Pimblico Cay	Exumas	Great Bahama Bank	2002	0	0	1	1	1	0	0	0	0	0	0	0	yes	-76.245273	23.82085087	0.56889974	1	0.60593663	1	Bradley and Norton 2009
1	East Cay	Turks	Turks Bank	2005	0	0	1	1	1	0	0	0	0	0	0	0	yes	-71.08766117	21.35626438	0.45983334	0	0.34765135	0	Bradley and Norton 2009
1	Five Cays	Providenciales	Caicos Bank	2004	0	0	1	1	1	0	0	0	0	0	0	0	yes	-72.25347595	21.73571485	0.67181002	1	0.64640206	1	Bradley and Norton 2009
1	Long Cay 1	Caicos	Caicos Bank	2005	0	0	1	1	1	0	0	0	0	0	0	0	yes	-71.55932949	21.46496913	0.37200421	0	0.42098684	0	Bradley and Norton 2009
1	Middle Caicos Island	Middle Caicos	Caicos Bank	2005	0	0	1	1	1	0	0	0	0	0	0	0	yes	-71.73850402	21.79451798	0.52989498	0	0.63451857	1	Bradley and Norton 2009
1	Northern Coast	East Caicos	Caicos Bank	2004	0	0	1	1	1	0	0	0	0	0	0	0	yes	-71.54864698	21.73053634	0.34503012	0	0.51487084	0	Bradley and Norton 2009
1	SixHills Cay	South Caicos	Caicos Bank	2004	0	0	1	1	1	0	0	0	0	0	0	0	yes	-71.62871426	21.4609293	0.40139161	0	0.4300922	0	Bradley and Norton 2009
1	Cayo Felipe el Chico	Ciego de Avila	Cuba	2000	0	0	0	1	1	0	0	0	0	0	0	0	yes	-78.62343676	22.61126809	0.07856816	0	0.06022084	0	Bradley and Norton 2009
1	Alcarraza	Culebra	Puerto Rico	2005	0	1	1	1	1	1	1	0	0	0	0	0	no	-65.36915186	18.3612937	0.55495771	1	0.60951306	1	Bradley and Norton 2009
1	Cayodel Agua	Culebra	Puerto Rico	2005	0	1	1	1	1	1	1	0	0	0	0	0	no	-65.34751716	18.31155404	0.57284807	1	0.61396437	1	Bradley and Norton 2009
1	Geniqui	Culebra	Puerto Rico	2005	0	1	1	1	1	1	1	0	0	0	0	0	yes	-65.2303426	18.33800848	0.6128579	1	0.64792492	1	Bradley and Norton 2009
1	Lobito Cay	Culebra	Puerto Rico	2005	0	1	1	1	1	1	1	0	0	0	0	0	yes	-65.39179172	18.334044	0.54992129	1	0.6030488	1	Bradley and Norton 2009
1	Matojo Cay	Culebra	Puerto Rico	2005	0	1	1	1	1	1	1	0	0	0	0	0	yes	-65.28936162	18.3366102	0.59923805	1	0.63229838	1	Bradley and Norton 2009
1	Mona Island	Mayaguez	Puerto Rico	2005	0	1	1	1	1	1	1	0	0	0	0	0	yes	-67.89274288	18.0829054	0.3806807	0	0.44304819	0	Bradley and Norton 2009
1	MonitoIsland	Mayaguez	Puerto Rico	2005	0	1	1	1	1	1	1	0	0	0	0	0	yes	-67.95272452	18.15534987	0.37922547	0	0.44291847	0	Bradley and Norton 2009
1	Raton	Culebra	Puerto Rico	2005	0	1	1	1	1	1	1	0	0	0	0	0	no	-65.3529545	18.31408612	0.57052287	1	0.61386871	1	Bradley and Norton 2009
1	Yerba Cay	Culebra	Puerto Rico	2005	0	1	1	1	1	1	1	0	0	0	0	0	no	-65.35368294	18.31890226	0.60089089	1	0.60568102	1	Bradley and Norton 2009
1	Cockroach Island	St. Thomas	Leeward Islands	1999	1	1	1	1	1	1	0	0	0	0	0	0	yes	-65.059803	18.40400186	0.64122451	1	0.70173689	1	Bradley and Norton 2009
1	Flat Cay	U.S. Virgin	Leeward Islands	1999	1	1	1	1	1	1	0	0	0	0	0	0	no	-64.98987813	18.31678798	0.68042398	1	0.69941629	1	Bradley and Norton 2009
1	Frenchcap	St. Thomas	Leeward Islands	1999	1	1	1	1	1	1	0	0	0	0	0	0	yes	-64.8511411	18.23201942	0.74536092	1	0.71701942	1	Bradley and Norton 2009
1	Saba Cay	St. Thomas	Leeward Islands	1999	1	1	1	1	1	1	0	0	0	0	0	0	yes	-64.99994513	18.30547486	0.67884103	1	0.70223277	1	Bradley and Norton 2009
1	Sula Cay	St. Thomas	Leeward Islands	2005	1	1	1	1	1	1	0	0	0	0	0	0	yes	-65.05708202	18.40295508	0.64130047	1	0.70263328	1	Bradley and Norton 2009
1	Broken Jerusalem	Ginger	Leeward Islands	2005	1	1	0	0	0	0	0	0	0	0	0	1	yes	-64.45742644	18.40481123	0.82184837	1	0.78930934	1	Bradley and Norton 2009
1	CooperIsland	Cooper	Leeward Islands	2005	1	1	0	0	0	0	0	0	0	0	0	1	yes	-64.50729837	18.38084467	0.83986718	1	0.78942431	1	Bradley and Norton 2009
1	GingerIsland	Ginger	Leeward Islands	2005	1	1	0	0	0	0	0	0	0	0	0	1	yes	-64.47540989	18.3901361	0.82824697	1	0.78939413	1	Bradley and Norton 2009
1	Great Tobago	Jost van Dyke	Leeward Islands	2005	1	1	0	0	0	0	0	0	0	0	0	1	yes	-64.82442398	18.445403	0.73017686	1	0.74129549	1	Bradley and Norton 2009
1	Dog Island	Anguilla	Leeward Islands	2005	0	1	1	1	1	1	1	0	0	0	0	0	yes	-63.25352797	18.28080414	0.43273322	0	0.55800884	0	Bradley and Norton 2009
1	Sombrero Island	Anguilla	Leeward Islands	2005	0	1	1	1	1	1	1	0	0	0	0	0	yes	-63.42375689	18.60016155	0.41738014	0	0.60199126	1	Bradley and Norton 2009
1	Pelican Key	St. Maartin	Leeward Islands	2004	0	0	1	1	1	0	0	0	0	0	0	0	yes	-63.0963641	18.02989895	0.45784087	0	0.57246831	1	Bradley and Norton 2009
1	Old Booby Hill	Saba	Leeward Islands	2004	1	1	1	1	1	0	0	0	0	0	0	0	yes	-63.21802762	17.63453294	0.54907843	1	0.7489192	1	Bradley and Norton 2009
1	Fort Bay	Saba	Leeward Islands	2004	1	1	1	1	1	0	0	0	0	0	0	0	yes	-63.24425825	17.61521272	0.54550597	1	0.74264077	1	Bradley and Norton 2009
1	Great Point	Saba	Leeward Islands	2002	1	1	1	1	1	0	0	0	0	0	0	0	yes	-63.24279125	17.64779146	0.54674866	1	0.74560484	1	Bradley and Norton 2009
1	Sulphur Mine	Saba	Leeward Islands	2004	1	1	1	1	1	0	0	0	0	0	0	0	yes	-63.23128438	17.64470804	0.54888395	1	0.74747842	1	Bradley and Norton 2009
1	Well's Bay	Saba	Leeward Islands	2004	1	1	1	1	1	0	0	0	0	0	0	0	yes	-63.25134949	17.64089519	0.54534871	1	0.74234731	1	Bradley and Norton 2009
1	Gallow's Bay	St. Eustatius	Leeward Islands	2003	1	1	1	1	1	0	0	0	0	0	0	0	yes	-62.98441106	17.47688851	0.52722262	0	0.72194608	1	Bradley and Norton 2009
1	Tumble Down Dick Bay	St. Eustatius	Leeward Islands	1998	1	1	1	1	1	0	0	0	0	0	0	0	yes	-62.99733659	17.50046103	0.53114804	1	0.72865042	1	Bradley and Norton 2009
1	Desirade Island	Desirade	Leeward Islands	2002	0	0	2	2	2	2	2	0	0	0	0	0	yes	-61.050047	16.32086	0.46144594	0	0.49598748	0	Bradley and Norton 2009
1	NE Falaises	Marie Galante	Leeward Islands	2002	0	0	1	1	1	1	1	0	0	0	0	0	yes	-61.23836337	15.98243911	0.47748803	0	0.43471452	0	Bradley and Norton 2009
1	St. Barts	St. Bartholomew	Leeward Islands	2002	0	0	2	2	2	0	0	0	0	0	0	0	yes	-62.833333	17.9	0.46078745	0	0.56896517	1	Bradley and Norton 2009
1	Vieux Fort	Marie Galante	Leeward Islands	2002	0	0	1	1	1	0	0	0	0	0	0	0	yes	-61.30383053	15.97769328	0.42937935	0	0.51810767	0	Bradley and Norton 2009
1	Burgaux	Martinique	Leeward Islands	2004	0	0	1	1	1	0	0	0	0	0	0	0	no	-60.8390718	14.40905039	0.50240334	0	0.50489867	0	Bradley and Norton 2009
1	Desirade	Martinique	Leeward Islands	2005	0	0	1	1	1	0	0	0	0	0	0	0	yes	-60.87394765	14.38850216	0.49524775	0	0.49318387	0	Bradley and Norton 2009
1	Perce	Martinique	Leeward Islands	2004	0	0	1	1	1	0	0	0	0	0	0	0	no	-60.83786703	14.41432421	0.49127762	0	0.50630095	0	Bradley and Norton 2009
1	Bird Rock	Barbados	Windward Islands	2005	1	1	1	1	1	1	1	1	1	1	1	1	yes	-59.61929915	13.33077013	0.48419292	0	0.45881327	0	Bradley and Norton 2009
1	Carriacou Complex	Grenada	Windward Islands	2002	0	0	1	1	1	0	0	0	0	0	0	0	yes	-61.44287571	12.50357914	0.57722026	1	0.35423159	0	Bradley and Norton 2009
1	Green Cay	Grenada	Windward Islands	1954	0	0	1	1	1	0	0	0	0	0	0	0	yes	-61.58929219	12.22150505	0.67508556	1	0.54849191	0	Bradley and Norton 2009

Presence and Absence	Island Name	Island Group	Major Chain	Survey Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	DEM Available	Longitude	Latitude	Near Zone Probability	Near Prediction	Pelagic Zone Probability	Pelagic Prediction	Data Source
1	LittleTobago	Tobago	South America	2004	1	1	1	1	0	0	0	0	0	0	0	0	yes	-60.50228175	11.29813454	0.49710584	0	0.28413713	0	Bradley and Norton 2009
1	St. Giles	Tobago	South America	2004	1	1	1	1	0	0	0	0	0	0	0	0	yes	-60.52160509	11.35611847	0.50160749	0	0.29911387	0	Bradley and Norton 2009
1	Bonaire	Bonaire	Bonaire	2014	1	1	0	0	0	0	0	0	0	0	0	0	yes	-68.238534	12.178361	0.56283905	1	0.43230627	0	Delnevo 2014
1	El Blanquilla Island	Venezuela	Central Caribbean	1994	1	1	0	0	0	0	0	0	0	0	0	0	yes	-64.59356494	11.84778755	0.55657232	1	0.66369053	1	Bradley and Norton 2009
1	La Orchila Island	Venezuela	Central Caribbean	2005	1	1	0	0	0	0	0	0	0	0	0	0	yes	-66.129629	11.794925	0.54323862	1	0.76810997	1	Bradley and Norton 2009
1	Isla los Hermanos	Venezuela	Central Caribbean	2005	1	0	0	0	0	0	0	0	0	0	0	0	yes	-64.42296169	11.79435621	0.51785909	0	0.60418623	1	Bradley and Norton 2009
1	Los Roques Island	Los Roques	Central Caribbean	2005	1	1	0	0	0	0	0	0	0	0	0	0	yes	-66.61973401	11.78615282	0.44292589	0	0.69196154	1	Bradley and Norton 2009
1	Little Scrub Island	Anguilla	Leeward Islands	2011	0	0	2	2	2	1	0	0	0	0	0	0	yes	-62.95633782	18.30266735	0.4669675	0	0.56050747	1	Hodge 2011
1	Mount Diaboltin	Dominica	Leeward Islands	0	0	0	1	1	1	0	0	0	0	0	0	0	yes	-61.4406229	15.48627476	0.51197424	0	0.56717904	1	Levesque and Yesou 2005

Appendix D: *Puffinus l. loyemilleri* Shapefile

Rank	Name	Island Group	Main Group	Last Survey	Jan	Feb	Mar	Apr	Near Zone Probabilities	Pelagic Zone Probabilities	Near Prediction	Pelagic Prediction	Mean Probability	Longitude	Latitude
1	Las Tortuguillas	La Tortuga	Venezuela	Unknown	1	1	0	0	0.616831855	0.677966982	1	1	0.64739942	-65.432864	10.960643
2	Bubies Bajo	La Roques	Venezuela	Unknown	1	1	0	0	0.443174100	0.655356121	0	1	0.54926511	-66.592058	11.827124
3	Klein Curacao	Curacao	Curacao	2002	1	1	0	0	0.557206838	0.106042388	1	0	0.33162461	-68.645057	11.990196
4	Islote Sucre	San Andres	Columbia	Unknown	1	1	0	0	0.453308395	0.537400736	0	0	0.49535457	-81.690571	12.603526
5	Richmond Island	Tobago	Tobago	Unknown	1	1	1	1	0.465830037	0.219631194	0	0	0.34273062	-60.595526	11.218511
6	Puerto Real	Los Frailes Is.	Venezuela	1945	1	1	0	0	0.411088343	0.132688937	0	0	0.27188864	-63.736354	11.201269
7	Isla la Sola	Los Frailes Is.	Venezuela	Unknown	1	1	0	0	0.390784063	0.144042433	0	0	0.26741325	-63.569708	11.313722
8	Isla de Patos	Venezuela	Venezuela	Unknown	1	1	1	1	0.249369090	0.106204108	0	0	0.17778660	-61.868556	10.635148
9	Monjes del Sur	Los Monjes	Columbia	Unknown	1	1	0	0	0.280665122	0.018489911	0	0	0.14957752	-70.905577	12.346441